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The Canadian Entomologist

Vol. XC Ottawa, Canada, October 1958 No. 10

Gross Anatomy and Growth of the Reproductive System of the Black Vine Weevil, *Brachyrhinus sulcatus* (F.) (Coleoptera: Curculionidae)[1]

By W. T. CRAM[2]

Entomology Laboratory, Victoria, B.C.

The black vine weevil, *Brachyrhinus sulcatus* (F.), a parthenogenetic species, has been present as a minor pest of strawberry in the Pacific northwest for many years (Treherne, 1914; Downes, 1924; Wilcox, Mote and Childs, 1934). Recently Andison (1953) reported that the species has increased rapidly in numbers during the past several years. In this area *B. sulcatus* is now as important as, if not more important than, the serious pest of strawberry, the strawberry root weevil, *Brachyrhinus ovatus* (L.). Since most of the damage is done by the larvae, which feed on the strawberry roots, it is necessary to control the adults before they commence oviposition, especially on soils that have not been treated with insecticides. The adults emerge and feed on the strawberry foliage during the first week of harvest. Studies at the Victoria laboratory have shown that most or all of the crop is harvested before oviposition becomes general. Hence, an insecticide can be applied before oviposition becomes general if this date can be predicted by examining the reproductive system. Also, it is important to know the stage of development of the ovaries of those adults that overwinter and are found in the strawberry fields in late March and April, so that control measures can be applied before oviposition again becomes general.

During studies on the life history at the Victoria laboratory, the adults were observed to have an extended pre-oviposition period. The average pre-oviposition period of 35 weevils kept at 68°F. and 75 to 85 per cent relative humidity was 31.9 days, with a range of 27 to 43 days. The pre-oviposition period in the field was somewhat longer, depending upon weather conditions. In 1956 the average pre-oviposition period of 12 weevils reared singly in glass vials in the field was 49 days, with a range of 46 to 63 days. Smith (1932) reported a pre-oviposition period of four to ten weeks in Pennsylvania.

This is a report on the gross anatomy of the reproductive system of the ovipositing adult and on the growth of the system during the pre-oviposition period, the information being suitable for predicting the commencement of oviposition in the field.

Methods

Pre-pupae were collected during late April and May, 1954, at Corvallis and Gresham, Oregon, U.S.A., and reared through the pupal stage to adults. Upon transformation, the adults were reared singly in glass vials 3 inches long by 1/2 inch wide. The vials were closed with corks each having a 1/4-inch hole, which was plugged with waterproof plastic screening for ventilation. Vials were placed on the laboratory window sill and each contained a fresh strawberry leaf (Marshall variety) from the field as food for the weevil. Weevils did not feed for the first four or five days but fed voraciously thereafter. When possible, living specimens were dissected; however, most of the dissections were made from preserved material.

[1]Contribution No. 3784, Entomology Division, Science Service, Department of Agriculture, Ottawa, Canada; in part from a thesis presented in partial fulfilment of the requirements for the M.S. degree at Oregon State College, June, 1955.

[2]Associate Entomologist.

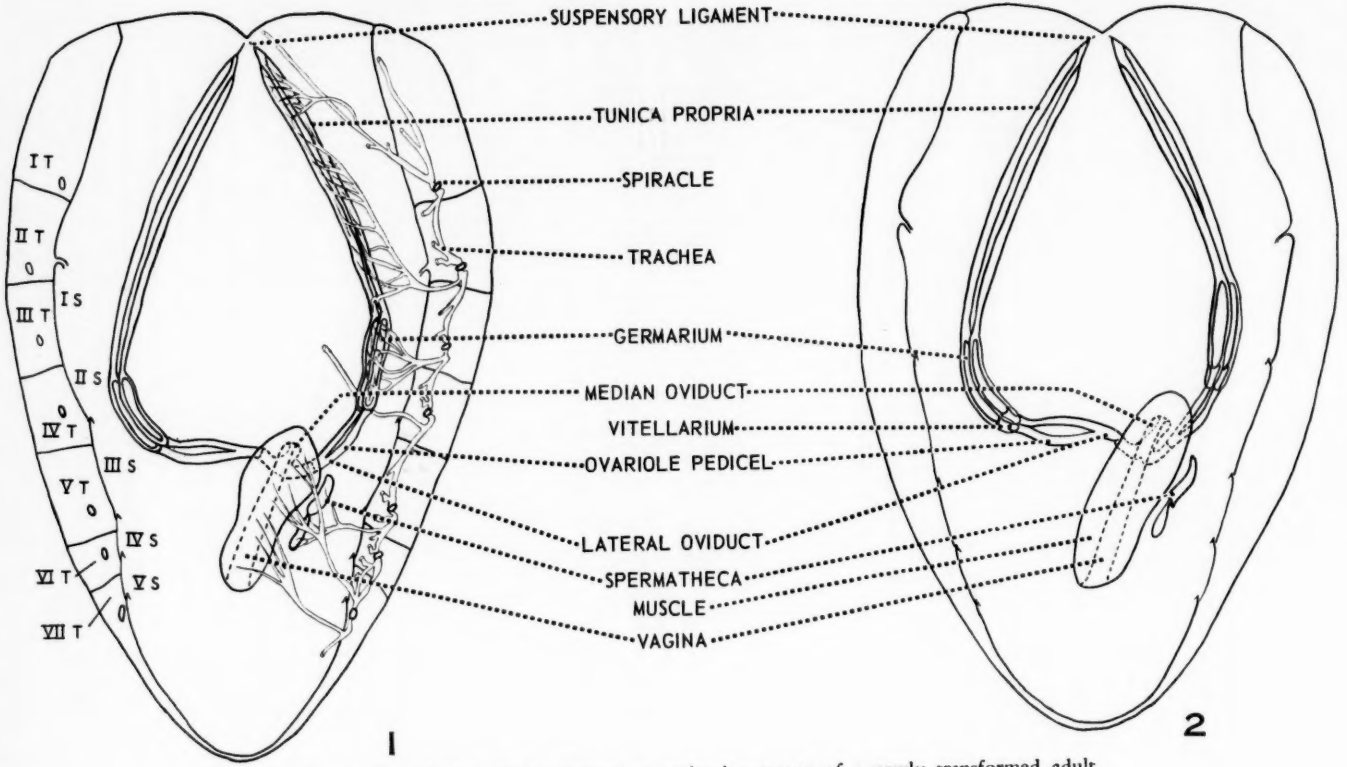

Fig. 1. Dorsal view of the internal reproductive organs of a newly transformed adult.
Fig. 2. 15-day-old adult.

SUSPENSORY LIGAMENT

Fig. 2. 15-day-old adult.

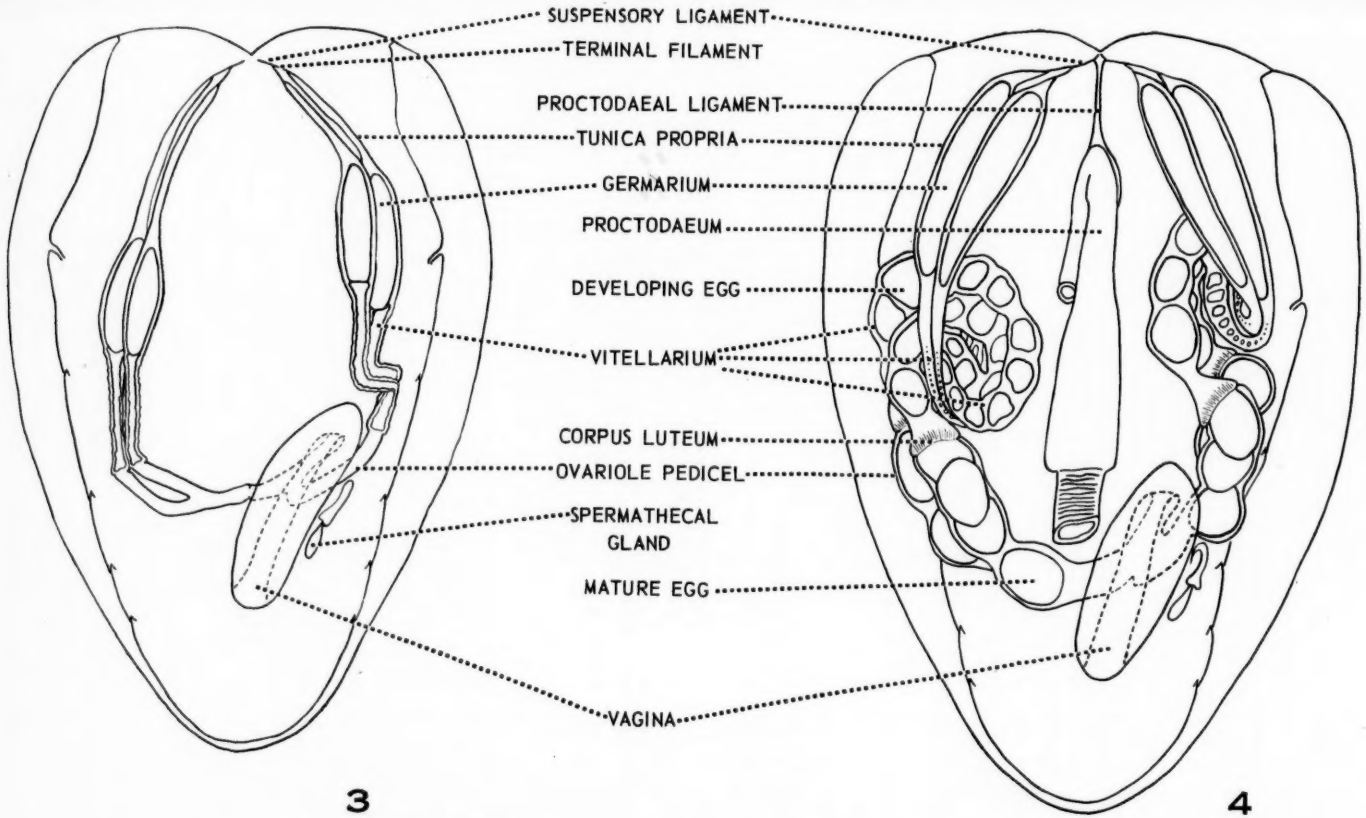

Fig. 3. 25-day-old adult.
Fig. 4. 28-day-old adult that has just commenced oviposition.

To determine the development of the reproductive system under field conditions, adults were collected from the Gresham area by sweeping an infested strawberry planting between 9:00 and 11:00 p.m. at periodic intervals during June, July, and August. Weevils were killed in Kahle's fixative and removed after 24 hours to 70 per cent alcohol for storage. They were dissected in 70 per cent alcohol.

Anatomy of the Mature Reproductive System

The mature female system in *B. sulcatus* is similar to that of other weevils (Ssilantjew, 1906; Snodgrass, 1935; Bissell, 1937; Tissot, 1938; Johnson, 1944; and Lenkowa, 1949). The system consists of four parts: the ovaries, the generative ducts, the accessory organs, and the external organs.

Ovaries

As in most weevils (Lenkowa, 1949), the two ovaries have each two ovarioles and lie in the laterodorsal abdominal cavities. The ovaries are supplied with a dense network of tracheae, and are surrounded by layers of fat bodies. The ovarioles of each ovary are not contained in a common membrane, nor are they connected, except at their anterior ends by the union of their terminal filaments at the suspensory ligament and at their posterior ends by the union of their pedicels at the lateral oviduct (Fig. 1).

Suspensory Ligaments.—The suspensory ligament of each ovary joins a large median ligament which originates at the anterior loop of the proctodaeum. This proctodaeal ligament is inserted in the ventral wall of the dorsal blood vessel where the latter passes under the posterior tip of the scutellum of the thorax (Fig. 4). A dorsal diaphragm is not evident. Lenkowa (1949) made no mention of a large proctodaeal ligament in the genus *Polydrosus* but reported that the suspensory ligament is attached to the dorsal diaphragm, whereas Nutting (1951) reported the atypical attachment of the suspensory ligament of acridoid grasshoppers, in which the fused ligaments arise from the ventral heart wall.

Egg Tubes.—In the mature system the tunica propria forms a loose, tough cover over each egg tube. Under this cover the large, anterior germarium is elliptical in shape, ranging from 1.04 to 1.73 mm. in length and from 0.25 to 0.47 mm. in width. The germaria lie parallel to the ventriculus, usually sloping toward the median dorsal line at their anterior ends (Fig. 4). At the slight constriction at the posterior end of the germarium, the follicular lining of the vitellarium begins.

At the anterior end of the vitellarium, oocytes are not visible under low magnification (X100). More posteriorly the oocytes are apparent and their size increases toward the ovariole pedicel. The vitellarium is tightly coiled in the abdominal cavity adjacent to the ventriculus and ventral to the germarium (Fig. 4). At the union of the vitellarium with the ovariole pedicel the thick-walled follicular vesicles and the dense tracheation common throughout the vitellarium both cease. At this point, yellow tissue within a swelling of the tube indicates the presence of the corpus luteum (Fig. 4).

Ovariole Pedicels.—The ovariole pedicels are greatly distended but, unlike those in the weevils studied by Lenkowa (1949), they are distinguishable as separate tubes that join at the lateral oviduct. Both the pedicels and the anterior ends of the lateral oviducts are thin, elastic membranes containing several mature eggs. Since there is no apparent difference between these two parts, the pedicels might be considered as part of the calyces.

Generative Ducts

Oviducts.—Although no difference is apparent between the tissues of the ovariole pedicels and the anterior portions of the lateral oviducts, a change in the tissue of the posterior portions is evident. The narrower, posterior portion appears slightly sclerotized, with longitudinal folds similar to those of the median oviduct. A definite line of union of the two portions of the lateral oviduct is evident, especially in the newly transformed adult (Fig. 1). Metcalfe (1932) found that the posterior portion, of ectodermal origin, joins with the anterior portion, of mesodermal origin, before the pupa of *Sitodrepa panicea* L. matures. Bissell (1937) and Tissot (1938) have, in the opinion of the present author, erroneously referred to the vitellaria and ovariole pedicels as the lateral oviducts in *Curculio caryae* (Horn.) and *Naupactus leucoloma* Boh., respectively.

The two lateral oviducts join at the median line near the intersegmental membrane of the third and fourth sternites. The resultant median oviduct loops sharply dorsally and anteriorly until it loops sharply posteriorly around the anterior tip of the spiculum gastrale and enters the thick musculature surrounding the vagina, where it joins with the latter (Fig.5).

Vagina.—The vagina, which is obscured anteriorly by heavy musculature and posteriorly by the ovipositor lobes, is a long, narrow tube with many longitudinal infoldings permitting expansion during oviposition (Fig. 5). The spermathecal duct opens dorsally at the anterior end of the vagina. According to Metcalfe (1932) the vagina is derived from a fusion of the primary invagination of the uterus and the primary invagination of the spermatheca. Hence, the primary opening of the spermathecal duct in the ninth sternite is now the opening, or vulva, of the vagina. A diverticulum of the vagina, the copulatory pouch, arises dorsally immediately posterior to the opening of the spermathecal duct. The vagina is slightly convoluted between the opening of the copulatory pouch and the basal plates of the ovipositor. These convolutions straighten when the ovipositor is extended.

The heavy musculature surrounding the vagina is comprised of outer longitudinal muscles that extend and retract the ovipositor and an inner layer of circular muscles that force eggs through the vagina.

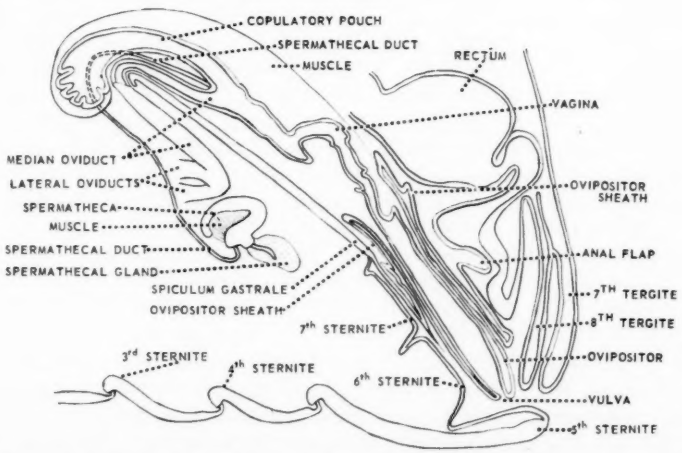

Fig. 5. Median longitudinal section of the vagina and the ovipositor. Spermatheca not sectioned.

Accessory Organs

Copulatory Pouch.—The copulatory pouch is a relatively large dorsal sac opening into the vagina (Fig. 5). The pouch curves anteriorly and ventrally over the median oviduct. There is much infolding of the wall of the pouch, especially at the blind anterior end. A circular muscle sheath encloses both the anterior end of the pouch and the median oviduct and holds them to the anterior tip of the spiculum gastrale. The function of the pouch in this parthenogenetic weevil is no longer one of receiving the male organ during copulation, but may be to hold mature eggs prior to oviposition.

Spermatheca.—The spermatheca is a heavily sclerotized organ lying on the right side of the vagina (Fig. 1). The organ is imbedded in fatty tissue and is well supplied with tracheae. The two ducts of the sickle-shaped spermatheca (Fig. 5) emerge from the enlarged 'handle'. The spermathecal duct emerges from the ventral wall of the 'handle' and loops anteriorly around the anterior end of the median oviduct into the muscle tissue surrounding the anterior tip of the spiculum gastrale and opens into the vagina just anterior to the opening of the copulatory pouch. The duct of the spermathecal gland emerges from the 'handle' posterior to the spermathecal duct. The spermathecal gland is bulbous and surrounds its short duct. A muscle sheath extends from the 'handle' to the back of the 'blade'. According to Snodgrass (1935) this muscle sheath has the function of pumping the spermatheca to eject sperms through the spermathecal duct into the vagina. Thus, although no males of *B. sulcatus* have ever been found, an apparently fuctional spermatheca is present. Lenkowa (1949) concludes that since there is no anatomical difference in the reproductive organs of the parthenogenetic and the bisexual species of the genus *Polydrosus*, the parthenogenesis originated recently, probably in the diluvial period.

External Organs

Ovipositor.—Externally five sternites and seven tergites are visible (Fig. 5). The sixth and seventh sternites are unsclerotized and are folded anteriorly above the fifth sternite. The spiculum gastrale lies between the seventh and eighth sternites. The eighth and ninth sternites are incorporated into the ovipositor. The sternum above the spiculum gastrale folds anteriorly to the base of the ovipositor, forming the ventral wall of the ovipositor's outer sheath, and then posteriorly forming the plates of the tubular ovipositor. At the base of the ovipositor the coxite of the eighth sternite, the first valvifer, is visible in cross-section as a sclerotized, lateroventral plate (Fig. 6). The first valvifer fuses with the sclerotized, main lateral plate, the second valvifer, which is the coxite of the ninth sternite. The ventral lobes are the membranous first valvulae and represent the gonapophyses of the coxites of the eighth sternite. Likewise, the dorsal lobes are the membranous second valvulae and represent the gonapophyses of the coxites of the ninth sternite. Normally the sclerotized second valvifers obscure the dorsal and ventral lobes of the ovipositor. Apically the second valifer gives rise to a stylus, which is the gonostylus (Michener, 1944). The sclerotized plates of the ovipositor have few setae but the apical portions of the second valvifers and the gonostyli have many pronounced setae (Fig. 6).

The dorsal wall of the ovipositor continues anteriorly for a short distance beyond the sclerotized plates before it rolls back posteriorly to form the dorsal wall of the ovipositor's outer sheath. Near the apex of the ovipositor this sheath again folds anteriorly and gives rise to an anal flap which covers the anal opening (Fig. 5).

The eighth tergite, which lies concealed beneath the seventh and last visible

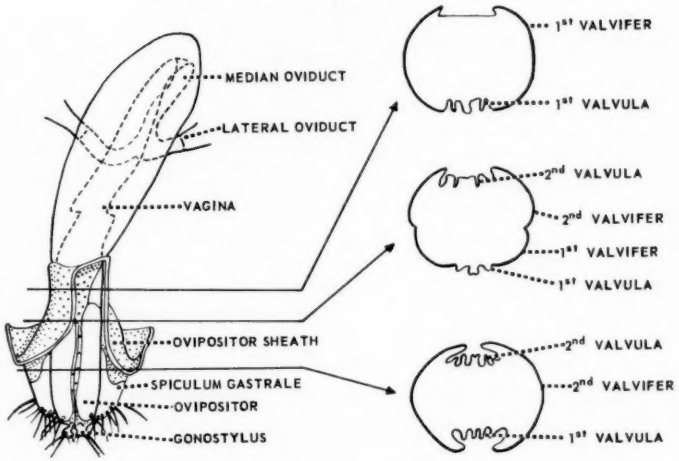

Fig. 6. Dorsal view and cross sections of ovipositor.

tergite, is separated from the latter by a deep intersegmental fold. The eighth tergite, often called the mantle, is visible when the ovipositor is everted. There are no spiracles in the eighth tergite. Additional tergites are not discernible (Fig. 5).

Spiculum Gastrale.—The presence of a spiculum gastrale, or sclerotized rod, is common in weevils. In *B. sulcatus* this structure is a spoon-shaped organ lying beneath the ovipositor and the vagina. Anteriorly the spiculum gastrale narrows to a slender sclerotized rod which extends into the abdominal cavity beneath the vagina as far as the intersegmental membrane of the second and third sternites (Fig. 5). The anterior tip of the rod is slightly broadened and to this area attach many of the muscles which operate the ovipositor. The broad, spoon-shaped, posterior end of the spiculum gastrale is heavily sclerotized at the lateral tips. Non-sclerotized tissue forms an open pocket in each of the antero-lateral wings of the spiculum (Fig. 6). Into these pockets are inserted the muscles from the vagina and the tergum. The main function of the spiculum gastrale, which is not of appendicular origin (Metcalfe, 1932), is to form a rigid base for the attachment of muscles that evert and retract the ovipositor.

Growth of the Reproductive System

Observations on Laboratory-Reared Weevils

Adults were killed at the four age groups of 0, 15, 25, and 28 days. One adult in the last group had laid 4 eggs and gave an example of a mature adult of known age (Fig. 4). Measurements were recorded (Table I) of the average ratio of the anterior advance of the larger germarium of the right ovary to the abdomen length of 10 weevils from each age group. The advance of the germarium was measured from the anterior tip of the germarium to the posterior tip of the fifth sternite. The length of the abdomen was measured from the posterior tip of the scutellum to the posterior tip of the fifth sternite.

Newly Transformed Adult.—In the newly transformed adult (Fig. 1) the ovaries are small and almost transparent. The slender, white germarium of each ovariole is 0.43 to 0.79 mm. long and 0.1 to 0.14 mm. wide. In the right ovary the germaria lie with their anterior ends directly above the posterior

TABLE I

Average measurements (mm.) of size and anterior advance of the germarium in ten *B. sulcatus* adults at 0, 15, 25, and 28 days of age when reared in the laboratory from pre-pupae collected in the field

Age days	Germarium[1]		Anterior advance of germarium[2]	Abdomen length[3]	Ratio of anterior advance to abdomen length
	Length	Width			
0	.63	.14	4.0	6.1	.65
15	.83	.18	4.2	6.4	.67
25	1.13	.23	4.7	6.3	.74
28	1.40	.29	5.5	6.6	.82

[1]Larger germarium of right ovary.
[2]On basis of distance from anterior tip of the larger germarium of the right ovary to the posterior tip of the fifth sternite.
[3]On basis of distance from the posterior tip of the scutellum to the posterior tip of the fifth sternite.

margin of the coxal cavity of the metathoracic leg, or 3.2 to 4.5 mm. from the posterior tip of the fifth sternite. A dense network of tracheae enters the tunica propria surrounding the germarium of each ovariole and holds them closely together, giving the appearance of connective tissue. There is no indication of vitellaria between the heavily tracheated germaria and their respective ovariole pedicels, which are noticeably lacking in tracheation. Beyond the anterior tip of each germarium, the dense tracheation enters the thin, transparent tube of tunica propria. The tunica propria extends to the anterior end of the abdomen, where it constricts and forms the terminal filament. Tracheae supplying the germaria at this early stage open at the third abdominal spiracle, whereas those of the transparent tubes open at the first and second abdominal spiracles (Fig. 1). There is a definite point of demarcation between the tissue of the anterior two-thirds and the posterior one-third of the lateral oviducts.

Fifteen-Day-Old Adult.—The germaria of the 15-day-old weevil (Fig. 2) show a very slight advance over their position at the time of transformation (Table I). The main point of difference is the presence of the vitellaria. Posterior to each germarium, a short length of tunica propria which is heavily tracheated and in close association with its adjacent tunica propria is visible. This part of the tube was previously occupied by the germarium, which has grown forward, leaving behind the follicular tissue forming the wall of the vitellarium. The ovariole pedicels are readily marked by their relative absence of tracheae. A considerable amount of fatty tissue obscures the ovaries.

Twenty-five-Day-Old Adult.—In the 25-day-old adult (Fig. 3) the germaria are considerably advanced and noticeably larger in size (Table I). The vitellaria are readily discernible, and in the right ovary a single convolution is present. The tunica propria of the vitellaria appears wrinkled and is slightly distended from the dense follicular tissue within.

Twenty-eight-Day-Old Adult.—When reared in the laboratory the 28-day-old adult (Fig. 4) has a system that is essentially mature. From the twenty-fifth day the ovaries undergo rapid growth (Table I). The germarium of each ovariole occupies the anterior extremity of the tunica propria. The convolutions of the vitellaria extend into the anterolateral abdominal cavities. The vitellaria are swollen with developing ova that attain mature size just anterior to the union

of the vitellaria with the ovariole pedicels. Both germaria and ova are visible through the semi-transparent tergum when the elytra are removed.

Observations on Field-Collected Adults

Ten specimens from each of 10 field samples collected in the Gresham area from June 7 to August 31, 1954, were examined and measured in the same manner as the weevils reared in the laboratory. Mature systems were also determined by the presence or absence of eggs in the calyces.

Adults commenced to emerge from the soil during the first week of June. Weevils collected on June 7 and June 17 had no development and very slight development, respectively, of their systems (Fig. 7). On June 30 the average development was equivalent to that of a 25-day-old laboratory-reared weevil. Although one specimen from the July 7 series was ovipositing, the series was on the average no further developed than the first series collected on June 7. This variation suggests that a large number of weevils emerged from the soil after the collection on June 30. The July 15 series was not so advanced as the June 30 collection but again one specimen was ovipositing. The July 24 series was well advanced, with 5 of 10 specimens ovipositing. The July 30 series had 7 of 10 weevils ovipositing; August 9, all 10; August 18, 9 of 10; and August 31, 7 of 8.

A comparison of these measurements and observations with those obtained from weevils reared from pupae in the laboratory made it possible to predict approximately the date on which general oviposition commenced in the field. These data also indicate that there were two populations of different ages present in the field after June 30. Although general oviposition by the later and more abundant population did not occur until July 24 members of the earlier population commenced oviposition on approximately July 7.

Summary

In the female reproductive system of the parthenogenetic weevil *B. sulcatus*, the suspensory ligaments of each ovary join a large, median, proctodaeal ligament, which is inserted into the ventral wall of the dorsal blood vessel. The two egg tubes of each ovary receive extensive tracheation from the first,

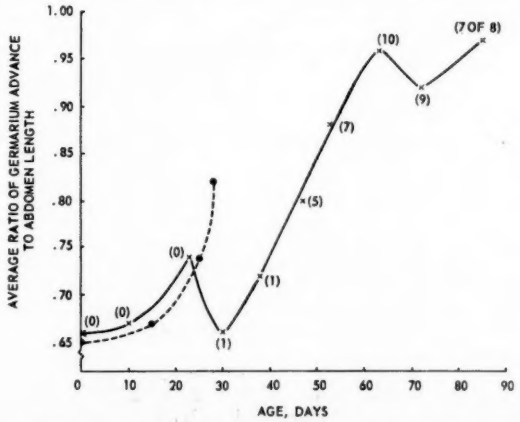

Fig. 7. Relationship between development of the reproductive systems of adults in the laboratory (broken line) and in the field (solid line). Ages of field-collected specimens calculated on basis of collection dates commencing on June 7, when adults first emerged. In parentheses: numbers out of ten weevils with mature systems.

second, and third abdominal spiracles. This tracheation readily distinguishes the egg tubes from the relatively non-tracheated pedicels of each ovariole. During times of peak oviposition the egg tubes are greatly swollen with developing ova and fill the anterolateral abdominal cavities. The ovariole pedicels are then greatly distended and serve for the storage of many mature eggs. The union of mesodermal and ectodermal tissue is evident in the lateral oviducts. The median oviduct and the vagina are a continuous tube leading to the vulva. Although this species is entirely parthenogenetic, both the copulatory pouch and the spermatheca are present in full detail. The ovipositor has as its base the first valvifers, which fuse with the large, sclerotized lateral plates, the second valvifers. The membranous first and second valvulae, or ventral and dorsal lobes respectively, are largely obscured by the second valvifers, which overlap them. Each second valvifer gives rise to a gonostylus at its apex.

The egg tubes of newly transformed adults have no vitellaria. The small, undeveloped germaria are situated immediately anterior to the ovariole pedicels. Anterior to each germarium the transparent tunica propria, which extends to the anterior end of the abdomen, is an empty tube. In the 15-day-old adult the germarium is slightly anterior to its previous position. A short vitellarium is apparent in each egg tube between the germarium and the ovariole pedicel. In the 25-day-old adult the germarium is much larger and is situated much more anteriorly. The vitellaria are readily apparent, those of the right ovary having single convolutions just posterior to the germaria. Under laboratory rearing conditions, the 28-day-old adult has essentially a mature system. Mature eggs may then be found in the calyces; the vitellaria are swollen with developing ova and the germaria are almost at the anterior extremity of the tunica propria.

Examination of periodic field collections of weevils during the pre-oviposition period is a satisfactory means of predicting when oviposition becomes general.

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Notes on Life-History and Larval Description of *Apamea apamiformis* (Guenée), a Pest of Wild Rice (Lepidoptera: Noctuidae)[1]

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Serious damage to the seeds of wild rice, *Zizania aquatica* L., is caused annually by the larvae of a noctuid species hitherto unidentified and with little of its life-history known. In the summer of 1957 larvae reared from eggs found in the heads of wild rice were determined as of the species concerned, and in March, 1958 an adult reared from the same lot was identified by Dr. D. F. Hardwick, Entomology Division, Ottawa as of *Apamea apamiformis* (Guenée).

The life-history of this species as now known is given here along with descriptions of the larvae in late instars. Since constant reference is made in the descriptions to Crumb's (1956) keys, his terminology has also been followed in that part of the paper.

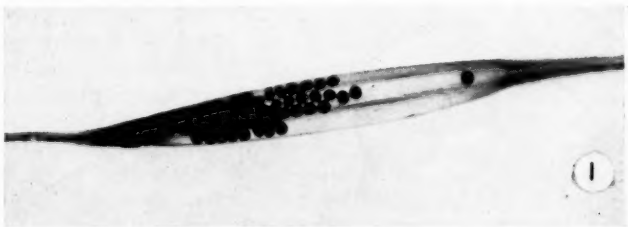

Fig. 1. Eggs of *A. apamiformis* in floret of wild rice.

Life-History Notes

The eggs are laid during July inside the floret at its base, in multiple rows. At the time of flowering, a slit appears at the base of the floret between the lemma and palet to allow the stigmas to protrude. If no pollen is trapped by them the floret may remain open for two or three days. The eggs are no doubt deposited within the floret during this period. The number of eggs found in four florets varied from 25 to 60, and hundreds of eggs are deposited in a single head.

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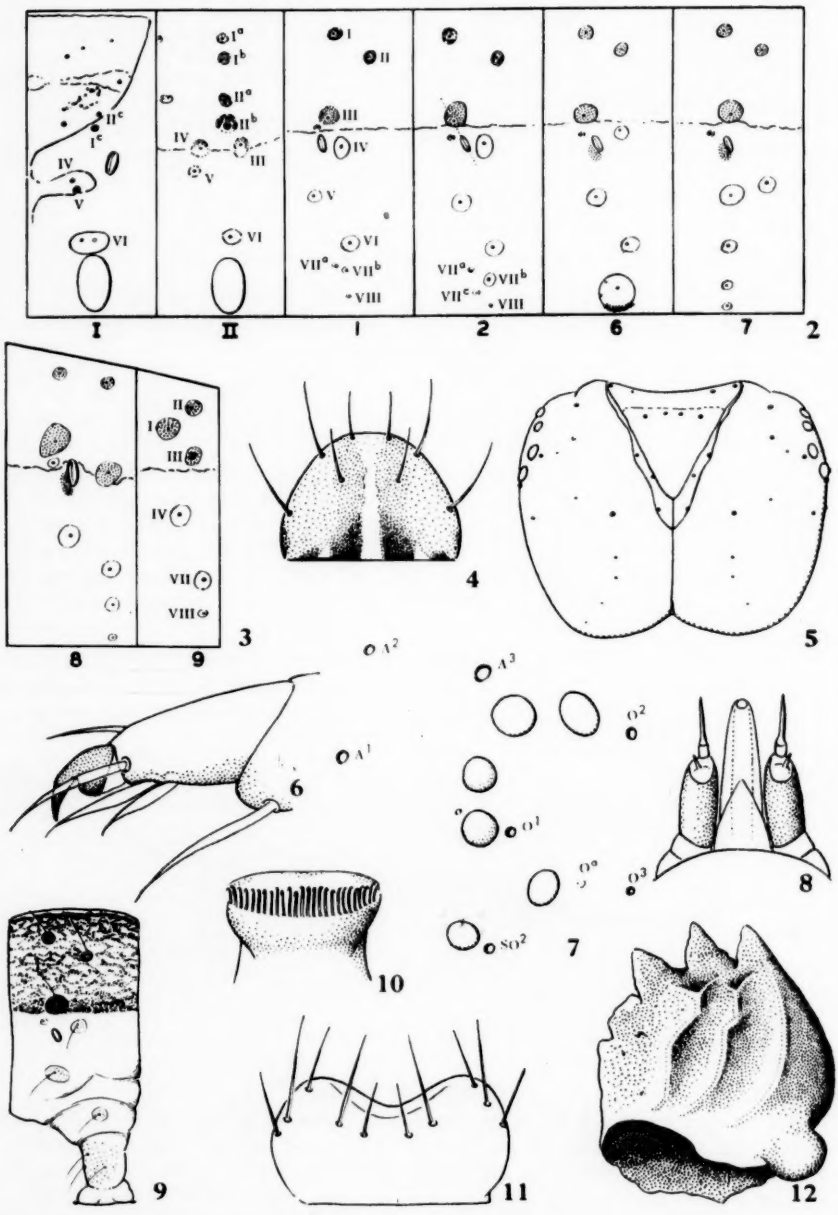

Figs. 2-12. Last-instar larva. 2, Setal map of first and second thoracic segments and 1st, 2nd, 6th, and 7th abdominal segments. 3, Setal map of 8th and 9th abdominal segments. 4, Anal shield (dorsal view). 5, Head (dorsal view). 6, Tarsus, claw, and apical setae. 7, Ocelli and surrounding setae. 8, Spinneret and labial palps. 9, Abdominal segment showing colour pattern. 10, Crotchets. 11, Labrum. 12, Mandible.

The early-instar larvae feed on the heads; those of later instars feed on the heads and within the leaf sheath and also bore into the stalks. More than one or two larvae are seldom found in a single stalk, but they are often present in association with a pyralid larva believed to be of a species of *Chilo* (the former are usually in the upper half of the stalk, the latter near the crown). The larvae overwinter in the late instars but apparently not in the last instar. Reared late-instar larvae left the host and disappeared into the soil in September; others not offered soil at that time remained in the stalks during the winter and burrowed into soil in the spring. In nature probably only those larvae managing to reach the shore, either by crawling from nearby hosts or by remaining in stalks that break off and drift ashore, complete their life-history (larvae were found in sections of stalks floating on the water). The few reared larvae that survived the winter and developed to the last instar fed on crushed green beans and peas. The single adult obtained emerged from its pupa in the soil a month after the larva had been brought from cold storage.

Descriptive Notes

Material Examined.—Six larvae in first instar and ten larvae in intermediate instars, labelled ER57-190; several larvae in intermediate instars, 2 larvae in last instar, and one adult, labelled ER57-240; eggs, labelled ER57-252. All material reared from eggs found in heads of wild rice in a rice paddy on the Canada Experimental Farm at Ottawa, Ont. In C.N.C.

Egg.—Smooth, subspherical, creamy when laid; about 0.5 mm. at its greatest and 0.4 mm. at its least diameter.

Larvae in All Instars Except First and Last.—Always with longitudinal stripes on dorsum, but with considerable variation in width of stripes especially in later instars. Some specimens with a narrow, pale middorsal line margined by a dark (often mottled) area extending to setigerous tubercle I; I and II on a pale area overlaid with darker reticulations and margined ventrally by a narrow pale line similar to the middorsal line; III on a broad dark (often mottled) stripe. Other specimens with the narrow pale line below II indistinguishable from the area containing I and II. Larva more conspicuously striped and not so dark on dorsum as in last instar.

Larva in Late Instars.—Placed without difficulty in Amphipyrinae, group 8 of Crumb's key by the following characters: venter of abdominal segment 10 confluent with subanal area between the median depressed area and base of the proleg; spinneret projecting normally, with an open apical or dorso-apical pore; five pairs of prolegs present; setigerous tubercule VII^{c} absent on abdominal segment 1; proleg with about 25 crotchets; crotchets uniordinal; oral face of mandible with ribs 2 and 3 elevated near the base to form blunt prominences; setigerous tubercle II^{c} on margin of cervical shield; tubercle II^{b} on mesothorax without a sclerotized bar connecting the tubercle with the adjacent ventral muscle attachments; midventral muscle attachments between prolegs forming a Y-shaped figure, the arms of which usually strongly impressed and anterior to the prolegs.

Placed in the genus *Apamea* [*Septis*] of Crumb's key by these characters: setae I^{c} and V on prothorax, II^{b} on the meso- and metathorax, and III on abdominal segment 9 each in a rather conspicuous, blackish, saucer-shaped depression, the setae themselves being weak, threadlike, and different in character from the adjacent setae; height of spiracle on abdominal segment I less than that of the prothoracic spiracle; anal shield rounded posteriorly. However, the larva a borer in the stems of its host; the long axis of the spiracle on

abdominal segment 2 in line with or but slightly anterior to seta 3 (contra Crumb's key).

Larva in Last Instar.—Head about 3.5 mm. in width. Body 30 to 35 mm. long and 5 or 6 mm. broad. Skin smooth. General colour brown.

Middorsal line narrow, pale, nearly continuous, distinct, and continuing onto thoracic and anal shields. Dorsum except for middorsal line with a pale ground colour overlaid by a dark-brown reticulation which is somewhat darker and less distinct near middorsal line and along ventral margin. Ventrum, including spiracular area, pale, of ground colour. Spiracles black-rimmed with yellowish centres. Setigerous tubercles I and II small, III moderate, all three dark brown; IV, V, and VI moderate, brownish; tubercules flat. Thoracic shield dark brown with pale middorsal and lateral lines. Head brown with a slightly darker reticulation; submedian arcs not always conspicuous.

Comments.—Last-instar larva easily placed in couplet 15 of Crumb's key to species of the genus *Apamea* [*Septis*], but its colour description not applicable to that given for either species of that couplet, i.e., *A. apamiformis* or *A. vultuosa*. Hence, the material examined by Mr. Crumb (four inflated larvae collected in 1881 and 1882) was probably misidentified years ago.

Reference

Crumb, S. E. 1956. The larvae of the Phalaenidae. *U.S. Dept. Agr. Tech. Bull.* 1135.

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A Useful Secondary Sex Character in *Dendroctonus* Bark Beetles

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The sex of the western pine beetle (*Dendroctonus brevicomis* Lec.) and the mountain pine beetle (*Dendroctonus monticolae* Hopk.) can be ascertained easily and with 100 percent accuracy by means of a secondary sex character on the seventh abdominal tergite of the male. This character can probably be used with equal accuracy to identify sex in all species of the genus *Dendroctonus*.

The need to distinguish between the sexes of adult bark beetles often arises in studies of biology, behavior, or response. The sexing procedure is laborious when large numbers of beetles are involved and external markings of sex are not known. It is then necessary to dissect each beetle to check the genitalia. Dissection is impossible when injury to the insect must be avoided.

External sexual markings in the genus *Dendroctonus* were first described by Hopkins (1909). He included: the size and opacity of the mandibles; the width of the front; the prominence of frontal tubercles and depth of frontal groove; the shape of the antennal club; the presence or absence of a transverse ridge on the anterior of the pronotum; the smoothness and shininess of the elytral declivity; and the degree of wrinkling of the declivity.

None of these characters occurs universally throughout the genus; one or a combination of several apply only to certain species groups. Furthermore, the differences between the male and female are largely a matter of degree so that the observer must rely heavily on judgment in deciding where the break occurs between male and female. As a result, separations made on the basis of these characters may not be reliable and will probably differ between observers.

[1]Maintained by the Forest Service, U.S. Department of Agriculture, in cooperation with the University of California, at Berkeley, California.

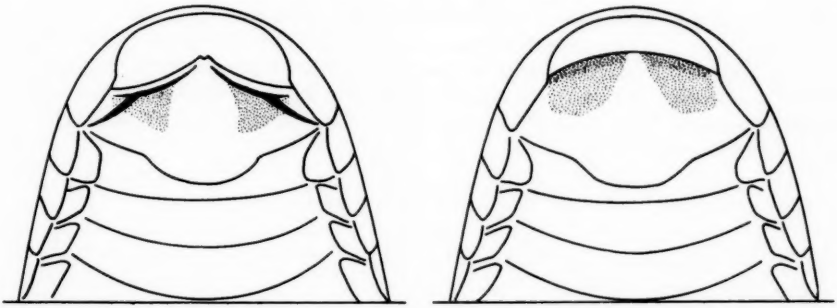

Figure 1. Schematic, dorsal view of exposed, rear part of adult abdomen (*Dendroctonus brevicomis* Lec.). Left, male with heavy pigmentation along angular rear margin of enlarged seventh tergite. Right, female with more homogeneous coloring and gently curved rearward margin (45x).

Entomologists do not seem to be generally aware that the seventh (penultimate) abdominal tergite is a useful and flawless indicator of sex in *Dendroctonus* bark beetles. In the males, this tergite is shaped to function as a stridulating organ. It is most easily recognized by the angular outline of its hind margin, which forms an angle of about 150 degrees pointing rearward (fig. 1). A sharply defined and very dark band of pigmentation along this margin makes the outline conspicuous.

The seventh tergite of the female differs in having a gently curved, instead of angular, rear margin. The distinct, dark band of pigmentation is lacking although the tergite often shows a gradient of increasing pigmentation rearward.

The sexual implications of the seventh tergite were noted by Hopkins at the turn of the century. Chapman (1955) used not the morphology of the seventh tergite itself but the sounds produced by the stridulating organ to identify sex of the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopk.), obtaining close to 100 percent accuracy.

A Test of Sex Determination

Small samples (10 to 50 specimens) of 11 *Dendroctonus* species were examined to determine the ease with which the seventh tergite could be used to distinguish males from females. The species were:

D. barberi Hopk.
D. brevicomis Lec.
D. convexifrons Hopk.
D. engelmanni Hopk.
D. frontalis Zimm.
D. jeffreyi Hopk.
D. monticolae Hopk.
D. parallelocollis Chap.
D. ponderosae Hopk.
D. pseudotsugae Hopk.
D. valens Lec.

Dissection of the genitalia served as a check on correctness of observation in all examinations. The seventh tergite of each species proved to have excellent diagnostic properties, easily distinguished even by an inexperienced assistant.

Larger samples of 1,300 *D. brevicomis* adults and 600 *D. monticolae* adults were examined to determine the reliability of the sex character, and again the

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ease with which it could be employed to distinguish sex. Without exception, the differences in the seventh tergite were sufficiently obvious to permit rapid sexing. Very rarely, an occasional beetle showed an advanced stage of pigmentation. Only then was extra precaution required to avoid mistakes; the darker integument tended to obscure, though not seriously, the typical color pattern of the diagnostic tergite.

The morphology of the seventh tergite varied little between or within species except for minor details which did not hinder sexing.

The sex character is so conspicuous that it can be easily seen by raising one elytron just enough to expose the stridulating organ or by slightly depressing the abdomen. Adults in full sexual development and those which have recently fed often show great distention of the abdomen. The hindmost part of the seventh tergite is then exposed, or nearly so, and sex can be recognized with little disturbance of the insect.

Identification of sex was found to be easiest with a dissecting scope of 15X magnification. A hand lens of 10X power is adequate where a microscope is not available.

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Notes on Parasitism of a Spruce Sawfly, *Diprion polytomum* (Htg.) (Hymenoptera: Diprionidae), in Czechoslovakia and Scandinavia[1]

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The European spruce sawfly, *Diprion hercyniae* (Htg.), was first found in Canada in 1930. An aerial survey in the following year showed that it was causing severe defoliation in an area of about 2,500 square miles in the Gaspé Peninsula, Quebec. In succeeding years it spread rapidly over wide areas in Eastern Canada (see, e.g., Baird 1937, Balch 1937). The work reported below was part of an attempt to control the sawfly by biotic agents.

Between 1935 and 1939 505,135 *Diprion polytomum* (Htg.) were collected in Czechoslovakia and Scandinavia by the Imperial Parasite Service (now the Commonwealth Institute of Biological Control) and shipped to Belleville where they were reared under the supervision of the senior author. At the time this work was done, *D. hercyniae* was not regarded as distinct from *D. polytomum*. However, the majority of the parasites undoubtedly emerged from *D. polytomum*. *D. hercyniae* was present in the imported material but apparently only in very small numbers, and some of the parasites that were reared in small numbers may have been specific on it.

A summary of the relative incidence of parasitism by the more important species in different generations of the host and notes on the emergence patterns

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of both host and parasites are given below. The detailed data are on file at the Belleville laboratory.

These notes supplement data given by Morris, Cameron, and Jepson (1937), who described various stages of many of the species of parasites listed, and by Finlayson and Reeks (1936), who listed the parasites reared from the material collected in Europe in 1932 to 1934 and from part of that collected in 1935.

Collection and Rearing

Collections, totalling 461,690 hosts, were made in 40 localities in Czechoslovakia from 1935 to 1939 and, totalling 43,445 hosts, in nine localities in Scandinavia (Finland, Sweden, and Norway) in 1938 and 1939. The sawfly has two generation each year in all areas in Czechoslovakia where collections were made except in the Riesengebirge (19,039 hosts collected), where, as in Scandinavia, there is only one generation each year.

In most cases larvae were collected and allowed to form cocoons before shipment to Belleville. In these circumstances only larval parasites should have been present, but *Agrothereutes abbreviator* (F.), *Dahlbominus fuscipennis* (Zett.), *Monodontomerus dentipes* (Dalm.), and other cocoon parasites often emerged. This might be explained by the fact that the sawfly larvae were allowed to spin cocoons in the area of collection where these parasites were present, so that some cocoons could have been parasitized after they had been formed.

Each cocoon was reared in a cotton-stoppered vial about 1 5/8 inches long by 3/8 inches wide, in a room at a temperature of approximately 24°C. and a relative humidity of 60 per cent. Rearing the cocoons individually enabled definite host-parasite data to be obtained, and prevented re-parasitism by chalcids.

Hosts of each generation were collected separately in the areas where the sawfly has two generations a year, and they were reared separately at Belleville so that differences in the parasitism between the two generations would be apparent. Hosts and parasites began to emerge from cocoons of the first generation in the same year in which they were collected, and from the second generation after storage for the winter at a temperature of approximately 1°C. Some sawflies and parasites emerged after two winters in cold storage, and a few sawflies emerged after three winters in storage.

Sex Ratio, Mortality, and Emergence Pattern of the Host

The percentage of male sawflies of the total reared each year ranged from about 25 to 50 with an average of about 37. This differs markedly from the ratio of males to females reared from collections of *D. hercyniae* made in Canada. A collection of the latter made in Quebec in 1939 produced 55 males and 52,082 females, or a ratio of about one male to 1,000 females. This figure agrees closely with the ratio in Canada reported by Balch (1939), of one male to 1,200 females.

An average of 41.0 per cent of cocoons of the first generation produced sawflies in the year in which they were collected; 4.6 per cent produced sawflies a year after collection, and 1.3 per cent after two years. From second-generation cocoons, 38.0 per cent emerged in the year after collection, 3.8 per cent emerged two years after collection, and 0.2 per cent after three years. From areas where a single generation of the sawfly occurred each year, percentages of emergence were 40.1 the year after collection, 0.8 after two years, and 0.3 after three years.

There was no emergence from 42.7 per cent of the cocoons. This was caused by mortality of the resting larval and the pupal stages. It is probable

that some of these cocoons were parasitized. Consequently the incidence of parasitism may have been higher than indicated by the figures given below.

Incidence of Parasitism

Twenty-seven species and two varieties of the hymenopterous parasites reared were identified. At least a further 27 species were identified only to genus. Six species and one variety of the tachinid parasites were identified. One specimen of Coleoptera was reared. Forty-five species were reared from the first generation from Czechoslovakia, 37 from the second, and 12 from the material from the Riesengebirge area. The Scandinavian material produced 16 species, of which seven were not also reared from the Czechoslovakian material.

Incidence of total parasitism, as measured by percentages of hosts from which parasites emerged, was 9.4, 26.1, and 21.3 of the first generation from Czechoslovakia collected in 1935, 1936, and 1937 respectively, and 9.9, 11.8, 10.7, and 6.9 for the second generation collected in 1935, 1936, 1937, and 1938, respectively; it was 17.2 in the single-generation material collected in the Riesengebirge, Czechoslovakia, in 1938; and it was 17.4 and 24.6 in the single-generation material collected in Scandinavia in 1938 and 1939 respectively.

In the early years of the work, identification of the species of parasites was hampered by lack of suitable taxonomic works. The publication of the paper by Morris, Cameron, and Jepson (1937) considerably facilitated identifications, but even in the later years many species were reared that could not be named by European specialists to whom they were sent. Separation of the species of the genus *Exenterus* was helped by publication of the paper by Cushman (1940). In the table below *Exenterus* spp. includes *E. confusus* Kerr., *E. tricolor* Rom., *E. vellicatus* Cush., and possibly *E. adspersus* Htg. *E. tricolor* was separated from the other species from 1936 on, *E. adspersus* was recognized from 1938 on, and *E. confusus* and *E. vellicatus* from 1939. The previously unknown males of *A. abbreviator* and *Ischnus polytomi* (Tschek) were discovered by rearing specimens from unfertilized eggs.

Morris, Cameron, and Jepson (1937) stated that some species of *Bathythrix*, *Gelis acarorum* L., some other species of *Gelis*, *Hemiteles sordipes* Grav., *Mesochorus dimidiatus* Holmg., *Mesochorus fulgurans* Curt., and *Pediobius* (= *Pleurotropis*) sp. are hyperparasites, and that *Dibrachys cavus* (Wlkr.), *Diglochis lophyrorum* Rshka., and *Hemiteles areator* Panz. sometimes may be hyperparasitic. Morris (1938) stated that *Eupelmella vesicularis* Retz. is a predator on *D. fuscipennis*. The beetle *Dryophilus pusillus* (Gyll.) may be a scavenger. There was no indication, either from the literature or from the rearing studies at Belleville, that the remaining species were anything but primary parasites. The species are all solitary parasites expect the chalcidoids *Amblymerus subfumatus* (Ratz.), *D. fuscipennis*, *D. cavus*, *D. lophyrorum*, *M. dentipes*, and *Pediobius* sp. From one to 60 individuals of both sexes of these chalcids emerged from individual host cocoons.

Numerous parasites emerged from the second rearing of first-generation cocoons, but not from the second rearing of second-generation cocoons. In general, total parasitism was twice as high in first-generation cocoons as in second-generation cocoons. In the regions where only one generation of the host occurred each year, total percentage parasitism was similar to that found in the first-generation cocoons from regions where two generations occur.

A preponderance of males occurred in all solitary parasitic species except *Exenterus* spp., with 57 per cent females, and *Drino inconspicua* (Meig.), with 53 per cent females.

TABLE I

TABLE I

Average percentage parasitism of chief parasites reared from *Diprion polytomum*

From 111,258 first-generation hosts collected in Czechoslovakia in 1935, 1936, and 1937		From 331,393 second-generation hosts collected in Czechoslovakia in 1935, 1936, 1937 and 1938		From 43,445 hosts collected in Scandinavia in 1938 and 1939	
Holocremnus ratzeburgi (Tschek)	6.8	*Holocremnus ratzeburgi* (Tschek)	5.2	**Drino bohemica* Mesn.	6.6
Lamachus marginatus (Brischke)	5.3	*Lamachus marginatus* (Brischke)	1.9	*Blondelia inclusa* (Htg.)	6.5
Exenterus spp.	2.1	*Exenterus* spp.	1.5	*Lamachus marginatus* (Brischke)	2.6
Amblymerus subfumatus (Ratz.)	1.3	*Exenterus vellicatus* Cush.	0.7	*Lamachus* sp.	1.7
Monodontomerus dentipes (Dalm.)	0.4	*Exenterus confusus* Kerr.	0.5	*Mesochorus dimidiatus* Holmg.	1.0
Drino inconspicua (Meig.)	0.4	*Drino inconspicua* (Meig.)	0.4	*Lamachus spectabilis* (Holmg.)	0.8
Cryptine spp.	0.3	*Exenterus tricolor* Rom.	0.3	*Euryproctini nr. *Zemiophorus*	0.8
Dahlbominus fuscipennis (Zett.)	0.3	*Lamachus* sp.	0.2	*Exenterus tricolor* Rom.	0.5
Dibrachys cavus (Wlkr.)	0.3	*Lamachus spectabilis* (Holmg.)	0.1	*Holocremnus ratzeburgi* (Tschek)	0.2
Hemiteles areator Panz.	0.2	*Bessa selecta* (Meig.)	0.1	*Mesochorus fulgurans* Curt.	0.1
Agrothereutes abbreviator (F.)	0.2			*Exenterus confusus* Kerr.	0.1
Lamachus spectabilis (Holmg.)	0.2	From 19,039 single-generation hosts collected in Czechoslovakia (Riesengebirge) in 1938			
Exenterus tricolor Rom.	0.1				
Aptesis basizonia var. *curtulus* (Kr.)	0.1	*Lamachus marginatus* (Brischke)	10.4		
Lamachus sp.	0.1	*Holocremnus ratzeburgi* (Tschek)	5.6		
Mesochorus dimidiatus Holmg.	0.1	*Lamachus* sp.	0.9		
Pimpla alternans Grav.	0.1	*Exenterus confusus* Kerr.	0.2		
Bathythrix spp.	0.1				
Hemiteles spp.	0.1				
Bessa selecta (Meig.)	0.1				
Gelis spp.	0.1				

*Reared from Scandinavia only.

The relative incidence of parasitsim by different species in different areas and generations is shown in Table I. Species that emerged from less than 0.1 per cent of the hosts are omitted from the table. From Czechoslovakia these were *Agrothereutes abbreviator* var. *hopei* (Grav.), *A. nubeculatus* (Grav.), *Agrothereutes* sp., *Aptesis basizonia* (Grav.), *Aptesis* sp., *Bathythrix strigosus* (Ths.), three species of *Bathythrix*, *Delomerista* sp., *D. lophyrorum*, *Eclytus ornatus* Holmg., *Erromenus* sp., *E. vesicularis*, a species of Euryproctini near the genus *Zemiophorus*, *E. adspersus*, *G. acarorum*, *H. sordipes*, three species of *Hypamblys*, *Hypsantyx impressus* (Grav.), *I. polytomi*, *Mastrus* sp., *M. fulgurans*, *Mesoleius* sp., *Olesicampe* sp., *Pediobius* (= *Pleurotropis*) sp., *Pimpla turionellae* (L.), *Pycnocryptus* sp., *Rhorus* (*Cyphanza*) sp., *Torocampus eques* (Htg.) (Hymenoptera), *Blondelia inclusa* (Htg.), *Blondelia nigripes* Fall., *Diplostichus janithrix* (Htg.), *Drino inconspicua* var. *inusta* Mesn. (Diptera), and *D. pusillus* (Coleoptera). Those from Scandinavia not included in the table are *Astiphromma* sp. near *leucogrammum* Holmg., *Hypamblys* sp., *Mesochorus* sp., and two species of *Mesoleius*. None of these five species from Scandinavia were reared from Czechoslovakia.

Of the important species that parasitize *D. polytomum* in Europe, only *Drino bohemica* Mesn., *A. basizonia*, *D. fuscipennis*, and some of the species of *Exenterus* became established on *D. hercyniae* in Canada (Reeks, 1953). Neither of the two most important European species, *Holocremnus ratzeburgi* (Tschek) and *Lamachus marginatus* (Brischke), have been recovered in Canada, though considerable numbers of each were liberated at times that coincided with the correct stage of the host in the field. Of the species liberated in Canada, 50 per cent of those found in Scandinavia only, 43 per cent of those found in central Europe only, and 29 per cent of those that occurred in both areas became established.

Patterns of Emergence of the Parasites

The parasites fell into a number of well-defined groups on the basis of the patterns of emergence in the laboratory. The comments below are generalizations only.

The chalcids *A. subfumatus*, *D. fuscipennis*, and *D. cavus* were found only in the first-generation cocoons and only in the first rearings of these. As they did not occur in the second-generation cocoons received at Belleville, parasitism may have occurred late in the fall, after the hosts to be sent to Belleville had been collected, and thus were carried over winter to parasitize the first generation of the succeeding year. Another chalcid, *M. dentipes*, unlike those just mentioned, occurred in the first and second rearings of both first- and second-generation cocoons.

The tachinids *Bessa selecta* (Meig.) and *D. inconspicua* and the ichneumonids *H. ratzeburgi*, *M. dimidiatus*, and *Hemiteles* spp. each emerged in the first rearings of the first- and second-generation cocoons. This suggests that there are at least two generations of these parasites each year in the field.

Exenterus spp., *I. polytomi*, *Lamachus marginatus*, and *L. spectabilis* (Holmg.) emerged in two rearings of the first-generation cocoons and in one rearing of the second-generation cocoons. Thus, all had emerged after one period of storage at low temperatures.

Several species of cocoon parasites showed similar behaviour by emerging in the first and second rearings of first-generation cocoons, but were not found in second-generation cocoons. This may indicate that no adults of these species were present between the time the sawflies had been collected and had spun their cocoons. The species in this group are *Agrothereutes abbreviator*, *A.*

nubeculatus (Grav.), *Aptesis basizonia* var. *curtulus* (Kr.), and *Pimpla alternans* Grav. Incidence of parasitism by these species was never higher than 0.2 per cent.

Delomerista sp. and *Lamachus* sp. differ from the others in that they emerged in the second rearing of the first-generation cocoons and in the first rearing of the second-generation cocoons. Thus, these species emerged only after exposure to a period of low temperature.

From the cocoons collected in the regions where only one generation of the host occurs each year, the parasites emerged in the first year of rearing except the several species of *Lamachus* which emerged in two successive years of rearing.

Acknowledgments

The authors wish to thank Dr. Charles Ferrière, formerly of the Department of Entomology, British Museum (Natural History), London, England, Dr. L. P. Mesnil, Commonwealth Institute of Biological Control, Feldmeilen, Switzerland, and Mr. R. A. Cushman, U.S. Department of Agriculture, Washington, D.C. for determining a number of specimens. Thanks are due also to Mr. W. J. Brown, Dr. W. R. M. Mason, Dr. O. Peck, Mr. G. E. Shewell, and Mr. G. S. Walley, Entomology Division, Ottawa, for determining some of the specimens.

Summary

Over half a million *Diprion polytomum* (Htg.) collected in Czechoslovakia and Scandinavia between 1935 and 1939 were reared individually in Belleville. An average of 37 per cent of the hosts reared were males. A total of 64 species of primary and secondary parasites were reared from the hosts. Average parasitism for first- and second-generation cocoons amounted to 9.4 and 9.9 in 1935, 26.1 and 11.8 in 1936, 21.3 and 10.7 in 1937, and 6.9 for the second generation in 1938. Average parasitism for single generation cocoons was 17.2 from Riesengebirge and 17.4 from Scandinavia in 1938, and 24.6 from Scandinavia in 1939. The most abundant parasites in Czechoslovakia were *Holocremnus matzeburgi* (Tschek), *Lamachus marginatus* (Brischke), *Amblymerus subfumatus* Ratz., *Exenterus* spp., *Monodontomerus dentipes* (Dalm.), and *Drino inconspicua* (Meig.). In Scandinavia the most important parasites were *Drino bohemica* Mesn., *Blondelia inclusa* (Htg.), *L. marginatus*, and *Lamachus* sp.

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Development, Behaviour, and Descriptions of Immature Stages of *Spilochalcis side* (Walk.) (Hymenoptera: Chalcididae)[1]

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The life-history, habits, and development of *Spilochalcis side* (Walk.) (*torvina* Cress.) were investigated at Belleville during studies on the parasites of needle miners, *Recurvaria* spp., attacking lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engelm.

Burks (1940) recorded this species as a parasite of species of the following families of Lepidoptera: Noctuidae, Gelechiidae, Eucosmidae, Glyphipterygidae, Plutellidae, Yponomeutidae, Coleophoridae, and Lyonetiidae. He also recorded it from Coleoptera (Curculionidae) and from Hymenoptera (Ichneumonidae and Braconidae). Doner (1936) stated that it parasitized small numbers of pupae of the cherry casebearer, *Coleophora pruniella* Clem., each year from 1930 to 1933 at the University of Wisconsin Experiment Station at Sturgeon Bay, Door County, Wisconsin. It was reared at Belleville on pupae of *Depressaria heracliana* (L.), *Anagasta kühniella* (Zell.), *Galleria mellonella* L., and *Pyrausta nubilalis* (Hbn.) (Lepidoptera); in the cocoons of *Apanteles atalantae* (Pack.), *A. congregatus* (Say), and *A. glomeratus* (L.) (Hymenoptera); and in an unidentified coleopterous casebearer.

This species has been recorded from 31 states of the United States and from British Columbia, Saskatchewan, Ontario, and Quebec (Burks, 1940). Those reared during the present study were from needle miners, *Recurvaria* spp., collected from lodgepole pine in California and Idaho.

This is the first record of this species being reared through a number of generations in a laboratory. Many specimens were reared on pupae several times larger than the ovipositing female. To prevent the parasite from being injured during oviposition, the larger pupae were glued in the grooves of corrugated cardboard with their soft ventral surfaces exposed. The parasitized material was incubated at 22.5±1° C. and 60 to 75 per cent relative humidity. The adults that emerged were fed daily with a 10 per cent aqueous solution of honey and sprayed twice daily with water.

Development and Behaviour

The adult of *S. side* emerges from the host pupa through an irregular hole. This hole is usually in the thorax regardless of host size: in 51 medium-sized hosts (*A. kühniella*), 98 per cent were in the thorax; in 26 larger hosts (*G. mellonella*), 89 per cent.

Mating usually takes place soon after the female emerges, though older females were observed to mate. It was usually preceded by a short courtship period, during which the male followed the female with his antennae waving up and down and his body swaying from side to side. When the male approached the female closely he placed his antennae between the abdomen and the slightly raised wings of the female and stroked her wings lightly. Then the male stood directly behind the female, swung his abdomen forward between his legs, and took up a mating position. Often in the early stages of copulation the female struggled and caused the male to lose his footing. When this happened the male was often left dangling in mid-air with his abdomen still attached to that of the female. The pairs remained *in copula* for 15 seconds to seven

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[2]Associate Entomologist.

minutes. The preoviposition period was six to eight days. Both males and females lived up to five months.

The adults are rather inactive at room temperature (22.5±1° C.) and in moderate lighting. When they are placed in direct sunlight or under a lamp they become active and the females begin ovipositing. As the female approaches a host pupa she usually moves her wings up and down without opening them. She then walks over the pupa, pierces it, and deposits as many as four eggs before leaving. Each puncture and oviposition, in the larger hosts, takes 15 minutes or longer. The eggs hatched 40 to 48 hours after deposition. When more than one egg was deposited in a small host pupa, such as *A. kühniella*, all the eggs usually hatched. Dissections showed that one first-instar larva usually killed the others. Most of the first-instar larvae had scars, and occasionally all died of wounds. By the second instar, there was usually only one parasite in each small pupa. In larger pupae (*G. mellonella*), two larvae sometimes continued development, and in one instance two parasites, one male and one female, emerged from a single host pupa. The parasite larvae fed within the host for six to 10 days. Defacation occurred after a non-feeding period of three to four days and pupation soon followed.

The adults emerged 20 to 25 days after the eggs were deposited. The size of the host influenced the length of the developmental period. In the smallest host, *Apanteles* spp., the average developmental time was 20 days; in the medium-sized host, *A. kühniella*, 23 days for the males and 25 for the females; in the largest host, *G. mellonella*, 25 days for both males and females.

Description of Stages

Egg

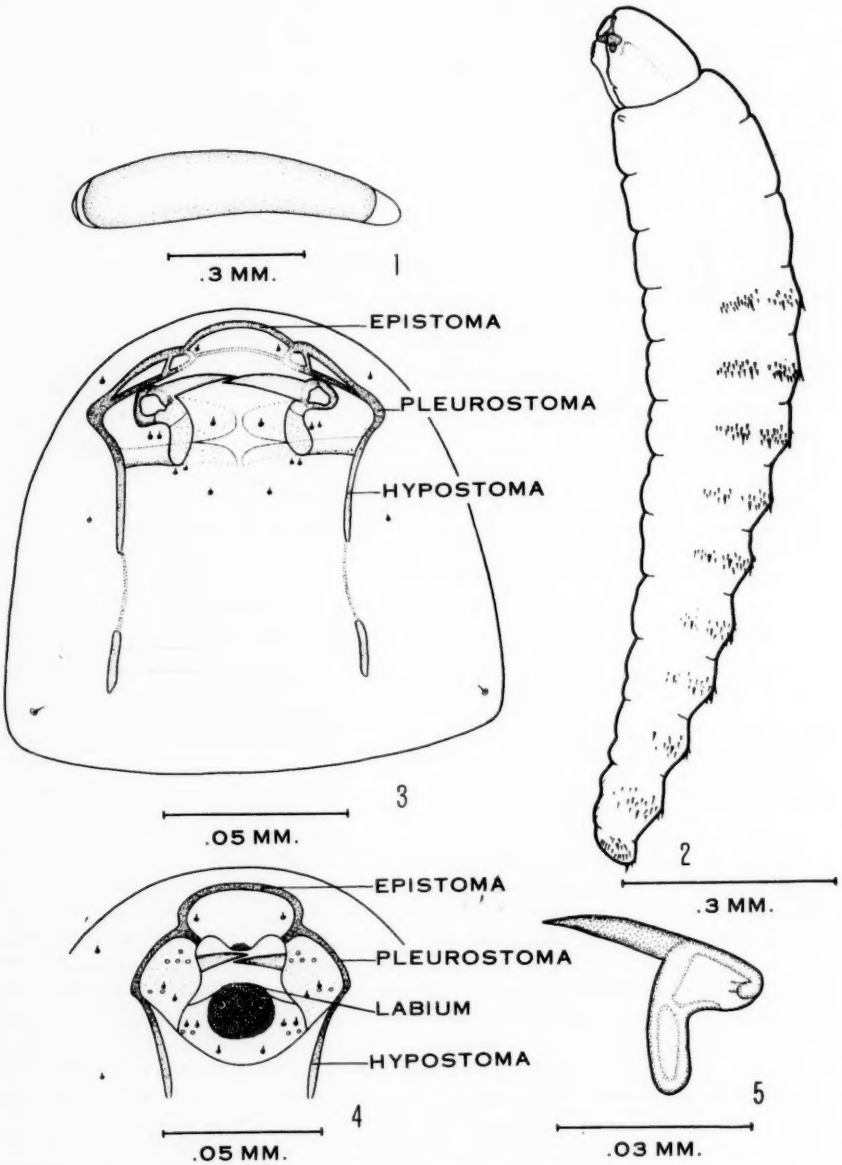
The egg (Fig. 1) is elongate, obtusely pointed cephalically, acutely pointed caudally, and widest one-third from the anterior end. The average length of 10 eggs, two to five hours old, was 0.75 mm. (range 0.70-0.80 mm.), and the average width at the widest point was 0.15 mm. (range 0.14-0.16 mm.). The egg is translucent white in colour. No surface sculpturing is visible. The micropylar area is represented by a small, slightly roughened area at the anterior end.

First Instar

The first-instar larva (Fig. 2) has 13 segments exclusive of the head, all being well defined and of about equal length. The average length of the larva is 1.08 mm. (range 0.87-1.21 mm.). The average width at the first abdominal segment is 0.21 mm. (range 0.17-0.24 mm.). The larva falls into Parker's (1924) group six, with a well-defined head, a body that tapers posteriorly, and segments of approximately equal length. Unlike the succeeding instars, definite spines occur on the lateral and dorsal surfaces of the abdomen. Though the pattern of the spines varies somewhat with the individual, there is a common basic pattern (Fig. 2). The thorax lacks spines. There are five spines larger than the remainder on each of the abdominal segments except the last two, where there are three. All spines point posteriorly. There are a pair of rod-like sensory organs on the anteroventral margin of the prothorax.

The tracheal system is readily visible through the cuticle of living larvae. There are two short branches from the two lateral tracheal trunks in the mesothoracic, metathoracic, and first abdominal segments. These branches extend dorsally, but no external openings were observed.

The head is hypognathous thimble-shaped, and lightly sclerotized (Figs. 3 and 4). The epistoma, pleurostoma, and hypostoma are well defined except near the posterior pleurostomal process. The labium (Fig. 4) is membranous

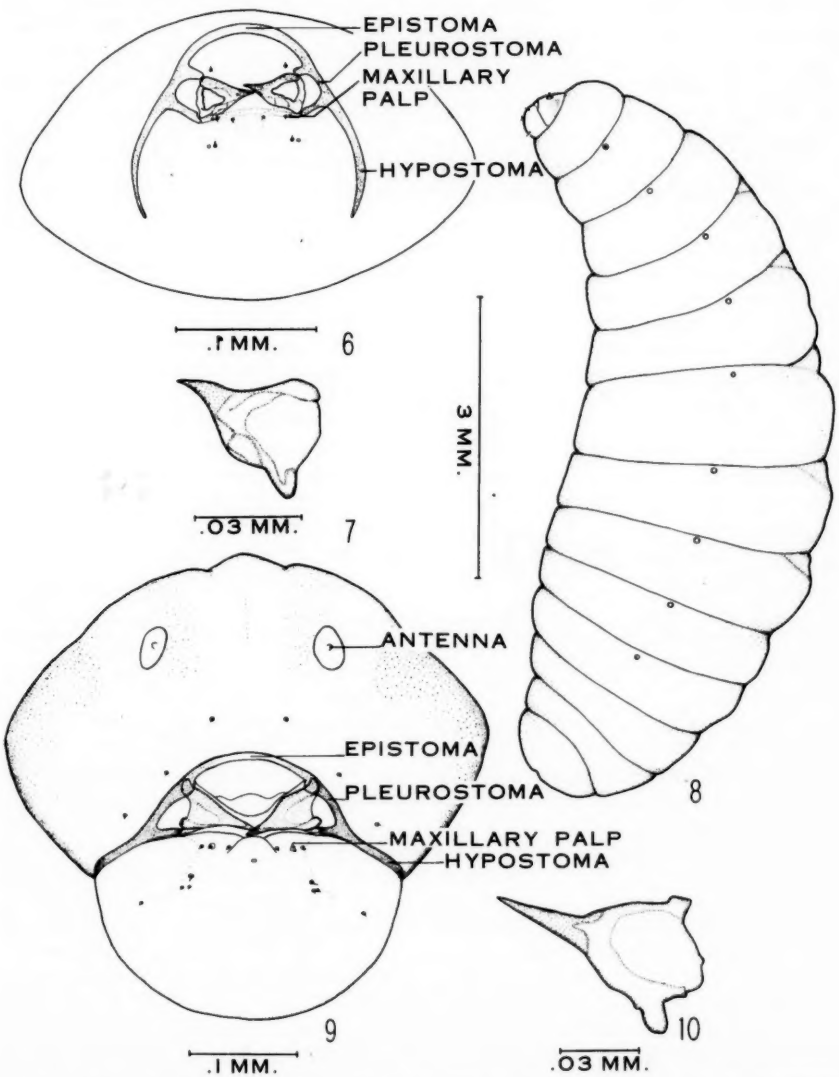


Figs. 1-5. *Spilochalcis side* (Walk.). 1, lateral view of egg; 2, lateral view of first-instar larva; 3, ventral view of cleared head capsule of first-instar larva; 4, oral area of first-instar larva before clearing; 5, right mandible of first-instar larva.

and protrudes ventrally just posterior to the mouth opening. It contains a circular area of closely set papillae that probably have a sensory function. There are a pair of larger, rod-shaped, papillae near the centre of this area. The mandible (Fig. 5) is 0.036 mm. (range 0.031-0.043 mm.) in length and is brownish-yellow in colour, darker near the tip.

Second Instar

The body of the second-instar larva is similar to that of the first instar



Figs. 6-10. *Spilochalcis side* (Walk.). 6, ventral view of head capsule of second-instar larva; 7, right mandible of second-instar larva; 8, lateral view of mature larva; 9, anterior view of head capsule of mature larva; 10, right mandible of mature larva.

except that it is more robust and the segments are poorly defined. The average length is 2.44 mm. (range 1.66-3.33 mm.) and the average width at the first abdominal segment is 0.53 mm. (range 0.44-0.67 mm.). No cuticular spines or setae were observed on the larvae examined.

There are nine pairs of open spiracles: on the mesothorax, metathorax, and the first seven abdominal segments. The openings are above the lateral tracheal trunks, to which they are connected by short tracheal branches. The diameter of the mesothoracic spiracle is 0.12-0.17 mm.

The head capsule of the second-instar larva is slightly pigmented. The average length is 0.23 mm. (range 0.12-0.34 mm.). No antennae were visible. The maxillary palps and all setae illustrated (Fig. 6) were located with a phase-compound microscope. The mandible (Fig. 7) is lightly pigmented and has an average length of 0.062 mm. (range 0.061-0.064 mm.).

Mature Larva

Dowden (1935) stated that there are five instars in *Brachymeria intermedia* (Nees), a closely related species. However, only three instars were observed in *S. side*.

The mature larva (Fig. 8) is more robust in body form than those of the previous instars and is more opaque and darker in colour. The length averages 4.12 mm. (range 2.16-5.87 mm.), and the width 1.00 mm. (range 0.70-1.34 mm.) at the first abdominal segment. No cuticular spines or sensory organs are present. The tracheal system is well developed. There are nine pairs of open spiracles, on the same segments as those in the second instar. The average diameter of the mesothoracic spiracle is 0.019 mm.

The head capsule (Fig. 9) is well differentiated and has an average length of 0.37 mm. (range 0.30-0.48 mm.). Small, dome-shaped antennae are present. The hypostoma, pleurostoma, and the lateral ends of the epistoma are brownish but the median part of the epistoma is colourless. A pair of one-segmented maxillary palps arise from a larger, lightly sclerotized basal plate. The mandible is broad, funnel-shaped at the base, and dark brown at the tip. The length of the mandible (Fig. 10) averages 0.083 mm. (range 0.067-0.077 mm.).

Prepupa and Pupa

The prepupa and pupa of *S. side* are similar to those of *B. intermedia* described by Dowden (1935).

Adult

The adult male was first described by Walker in 1843. The present author found that adults of the same sex reared on different hosts varied in size. Males reared in *Apanteles* spp. averaged 2.43 mm. in length, whereas males from *G. mellonella* averaged 3.62 mm. Females obtained from *G. mellonella* were often 4.71 mm. long.

Summary

Spilochalcis side (Walk.), which is a common parasite of lepidopterous pupae throughout the United States, was reared in the laboratory in the pupae of *Depressaria heracliana* (L.), *Anagasta kühniella* (Zell.), *Galleria mellonella* L. and *Pyrausta nubilalis* (Hbn.) (Lepidoptera); in the cocoons of *Apanteles atalantae* (Pack.), *A. congregatus* (Say) and *A. glomeratus* (L.) (Hymenoptera); and in an unidentified coleopterous casebearer.

Mating usually took place soon after the females emerged. It was usually preceded by a short courtship period. The pairs remained *in copula* for 15 seconds to seven minutes. The preoviposition period was six to eight days. Both males and females lived up to five months. A female deposits as many as four eggs in a host pupa. One first-instar larva usually killed the others.

Adult parasites emerged 20 to 25 days after the eggs were deposited. The distinguishing characters of the immature stages are described.

Acknowledgments

The author is grateful to Dr. O. Peck, Insect Systematics and Biological Control Unit, Entomology Division, Ottawa for identifying the species; and to the following officers of the Belleville laboratory: to Dr. H. C. Coppel for constructive criticism during the work, Miss M. E. Good and Mr. W. Kooiman who assisted with the rearing, and Mr. J. H. McLeod for criticizing the manuscript.

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Recoveries of Introduced Species of Parasites of the Winter Moth, *Operophtera brumata* (L.) (Lepidoptera: Geometridae), in Nova Scotia[1]

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Five species of parasites reared from European material were released at Oak Hill, near Bridgewater, Nova Scotia from 1954 to 1956 as biotic agents against the winter moth, *Operophtera brumata* (L.) which had been established in Nova Scotia since before 1950. Recovery collections were made annually from 1955 to 1957. This work is still in progress, and in 1957 releases were made in four additional localities. Results of establishment of parasites from releases from 1954 to 1956 are reported below.

The five species of parasites and the total numbers of adults released were as follows: *Cyzenis albicans* (Fall.) (Diptera: Tachinidae) 1954, 31; 1955, 1,008; 1956, 1,005; 1957, 250. *Agrypon flaveolatum* (Grav.) (Hymenoptera: Ichneumonidae) 1956, 436; 1957, 71. *Lypha dubia* (Fall) (Diptera: Tachinidae) 1955, 27. *Phobocampe crassiuscula* (Grav.) (Hymenoptera: Ichneumonidae) 1955, 204; 1957, 545. *Pimpla turionellae* (L.) (Hymenoptera: Ichneumonidae) 1955, 188.

Recovery collections have revealed no evidence of establishment of *L. dubia*, *P. crassiuscula*, or *P. turionellae*.

In May, 1955, attempts to recover *C. albicans* were unsuccessful. Rearing of 2,100 larvae of *O. brumata* collected in June and July after the release of *C. albicans* on June 3, yielded 32 puparia of *C. albicans* in the fall.

In June, 1955, to determine whether *C. albicans* might overwinter, a wire-screen cage was built over an infested small northern red oak, *Quercus rubra*

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L. var. *borealis* (Michx. f.), Farw., and five adults of the parasite *C. albicans* and additional host larvae were introduced into it. Clean sand was provided on the ground in the cage as a pupating medium for the host. In July, after all insect activity had ceased in the cage, the upper part of it was removed, the tree was cut off at the level of the sand and removed, and the lower part of the cage was covered with wire screen to form a ground cage about six inches in height. Early in the spring of 1956 holes were bored in one side of the shallow ground cage and glass vials were inserted to trap emerging insects, after the open top of the cage was covered with plywood to exclude light. Eleven *C. albicans* adults were recovered in the vials. On May 28, examination of all the sand in the bottom of the cage yielded four living puparia and 22 empty pupal cases of *C. albicans*. The failure to trap 50 per cent of the emerging adults was not considered to be significant because the experiment was successful qualitatively. This was the first evidence that this introduced parasite of the winter moth had overwintered in Nova Scotia.

In 1956, rearing of 1,700 larvae of the winter moth yielded 24 *C. albicans* puparia that had survived from the previous year in the release area.

In June 1957, 10,069 mature larvae of the winter moth were collected and reared to pupation. In November, the pupae were inspected individually and 49 puparia of *C. albicans* were found. In December, after moth emergence, dissection of the remaining host pupae yielded 232 pupae of *A. flaveolatum*. In 1957, total parasitism by these two introduced species was 2.8 per cent; parasitism by native Diptera was 4.8 per cent and by nematodes 0.3 per cent.

The fact that *A. flaveolatum* was recovered in such numbers the year after it was released indicates that it may become a more effective parasite than *C. albicans* on the winter moth in Nova Scotia.

Four years of investigation showed that larvae of the winter moth mature each year at approximately the same time, circa June 20, irrespective of the date of hatching of the overwintered eggs. Consequently the optimum dates for release of *C. albicans* and *A. flaveolatum* approximate June 5 and 10 respectively. At those dates the host larvae have reached the third and fourth stages respectively, and it appears that in those stages and in the ones following the optimum parasitism by these species occurs.

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Factors That Affect Host Finding by *Nasonia vitripennis* (Walk.) (Hymenoptera: Pteromalidae)[1,2]

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Adults of most species of insect parasites spend much time finding objects that influence their individual and collective well-being. The object found at any time is usually correlated with the physiological state of the parasite and with extrinsic factors existing at that time. From the standpoint of the species' economy, the most important objects to be discovered are hosts on which fertile parasite progeny can mature. Whether hosts are found and parasitized is influenced, to varying degrees with different parasite species, by whether the female has already found, or been found by, a male of the same species, and by whether she has already located food other than that provided by hosts. The present study is of factors that affect host finding by females of a pteromalid, *Nasonia vitripennis* (Walk.).

Life-history

N. vitripennis parasitizes the pupae of a large number of Diptera in nature, including species that develop as larvae in carrion, dung, rubbish, and on the young nestlings in birds' nests. A female parasite that has mature eggs drills through the host puparium with her ovipositor and lays eggs externally on the enclosed pupa. She then forms a feeding tube extending from the outside of the puparium to the pupa and sucks up fluid from the host tissues. This food significantly increases the number of mature eggs in the female's ovaries (Edwards, 1954b), and thereby affects her ability to parasitize hosts that she may find later. The parasite larvae feed and pupate, and the adults eclose approximately 24 hours before they bite one or more holes in the puparium and emerge. Experiments by the author showed that the size of a host pupa limits the number of parasites that mature on it, and that supernumerary larvae are eliminated by starvation: usually fewer than 20 adults emerged from puparia of the house fly, *Musca domestica* L. (Diptera: Muscidae), that were 6.0 ± 0.2 mm. long, and not more than 10 from puparia 5.0 ± 0.2 mm. long. *N. vitripennis* breeds continuously if hosts are available and if the temperature is sufficiently high; low temperature causes diapause in the mature larvae and development resumes after the temperature is raised.

Materials and Methods

N. vitripennis was reared continuously on the house fly, *M. domestica*, in the laboratory. The host laid eggs on absorbent cotton moistened in milk, and the mature larvae left this medium and formed puparia. The latter were exposed to the parasite adults and later were removed and reared at 25°C. until parasites emerged. The time from parasite egg laying to eclosion was about 16 days at this temperature. Other hosts used in certain phases of the study were *Calliphora vicina Desv.* (= *C. erythrocephala* (Meig.)) (Diptera: Calliphoridae) and *Polietes lardaria* (F.) (Diptera: Anthomyiidae), the larvae of which developed in meat.

The general effects of several environmental factors on the behaviour of the female parasite was tested in a modification of the olfactometer described

[1]Contribution No. 3845, Entomology Division, Science Service, Department of Agriculture, Ottawa, Canada; from a thesis submitted to the University of Oxford in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

[2]Edwards (1952) showed the precedence of the generic name *Mormoniella* over *Nasonia* for this species, on the basis of the principle of page precedence established at the International Congress of Zoology in Paris in 1948. However, this principle was rescinded at the succeeding Congress in Copenhagen in 1953, and the generic name thereby became *Nasonia*.

[3]Associate Entomologist.

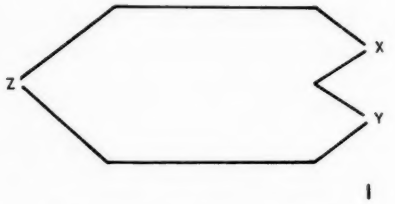

Fig. 1. Plan of olfactometer.

by Varley and Edwards (1953). The apparatus (Fig. 1) consisted of a chamber 38 cm. x 16 cm. x 0.6 cm. with the floor and roof of sheets of plate glass and the walls of strips of plate glass arranged to form two entrances, X and Y, at one end of the chamber and one, Z, at the other. Air was drawn through the apparatus from X and Y to Z at a rate of about one centimetre per second. The two air currents mixed very little along most of the length of the olfactometer but considerably at the downwind end, where the parasites entered. There was no physical barrier between the currents and therefore it was unlikely that an insect would be unable to rectify a "mistake" in choosing between them, as could more easily happen in a Y-tube type of olfactometer. Both freshly emerged and older females that had fed on hosts moved upwind and arrived at either X or Y. A light was suspended above and beyond the upwind end of the olfactometer and preliminary tests showed that it did not affect the direction of the parasite's movements.

Discovery of Mates

Approximately 40 per cent of the adult progeny of mated females of *N. vitripennis* reared were males. This percentage is similar to that recorded by Girault and Sanders (1910), whereas Graham-Smith (1919) and Cousin (1933) reared relatively fewer males. Unfertilized females produced only male progeny. Freshly-emerged females often disperse by flight from the emergence site, and males have very short wings and cannot fly; therefore, females that are not mated soon after they emerge usually produce only male offspring. The males begin to emerge first from each puparium and wait on or near it, where they court and mate with the females soon after the latter emerge. The opposite sex is, therefore, usually found from a shorter distance than in species in which the individuals do not develop gregariously. Light may assist the male in finding the female but is not essential, for copulation sometimes occurred in total darkness. It is probable, therefore, that olfactory or gustatory stimuli produced by the females attract the males either from short distances or after individuals of opposite sexes have met by chance. Both males and females may mature in the same host pupa; however, fertilization never occurred before emergence, probably because there was insufficient space inside the host puparium for courtship and mating.

Female Dispersal

Females of *N. vitripennis* that emerge in an environment such as a bird's nest, in which there often are successive host generations, may find suitable hosts inside the environment, whereas those that develop on hosts that have fed in carrion or dung may have to travel much further to locate another host-containing area. They may do this either by walking or by flying. A female on a flat surface walked about four or five millimetres per second at 25°C. and travelled upwind, usually in a fairly straight line. The effect of wind

direction on the direction of movement was, however, less evident when the insect was on an uneven substratum, as is usually encountered in nature. It is therefore probable that host-containing areas that are relatively distant from the site of parasite emergence are found usually either by flight alone or by alternate periods of flight and walking, but not by walking alone. According to Roberts (1933) *N. vitripennis* found and parasitized blow-fly pupae placed in containers 15 feet above the ground. Tests in the present study showed that freshly emerged females were more strongly attracted to light and flew more readily than older adults that had been parasitizing hosts for several days. This probably means that freshly emerged females fly and disperse widely whereas older ones that have found hosts do not. In darkness all females walked actively but flew very little.

Effects of Physical Factors on Searching by Females

Light

The effects of light on activity of females of *N. vitripennis* were not studied in detail. The greater attractiveness of light to freshly emerged females than to older ones and its significance in host-finding is indicated above.

Geotaxis

No pronounced geotactic reaction by either freshly emerged or older females was observed.

Temperature

The effects of temperature on the activity of females of *N. vitripennis* were not studied in detail, though it was noted that the rate of walking increased with increasing temperatures up to at least 30°C.

Humidity

As the host-containing areas may be in either very dry or very wet habitats a preference by the parasite female for either a high or a low relative humidity does not always aid her in locating a host environment but may affect her ability to find hosts within environments, such as carrion or dung, in which some dipterous species prefer dry and others moist micro-habitats for pupation. The olfactometer described above was used to study the general effects of different relative humidities on the female's behaviour. When the two air currents had been drawn over, respectively, anhydrous calcium chloride and water before they entered the apparatus, a humidity difference across the chamber was established. This was shown by the colour of narrow strips of cobalt chloride paper (for method of preparation see Solomon, 1945) placed at right angles to the direction of the air flow. The colour indicated distinct "dry" and "moist" areas along most of the length of the olfactometer, and a relative humidity of approximately 50 per cent, caused by mixing of the two air streams, at the downwind end. That the parasite females were neither attracted nor repelled by an odour of calcium chloride was shown in a preliminary test, in which two currents of air of the same relative humidity that had passed over, respectively, water, and anhydrous calcium chloride and water successively, were drawn through the olfactometer. It was, therefore, possible to study the general reactions of females to dry and moist conditions as they moved upwind from point Z. Similar results were obtained with freshly emerged females and with females that had oviposited and fed on hosts. Thirty-two females of the latter physiological state were tested: 20 of these entered the "dry" side and the other 12 the "moist" side of the olfactometer from Z; and 29 reached the entrance for "dry" air and only three the "moist" air entrance. There were 18 crossings from the "moist" to the "dry" side of the olfactometer and seven in the opposite direction.

This avoidance by the females of the moist air stream was confirmed in a second test, in which 14 females walked in succession inside the chamber for five minutes each: they remained for a total of 3,875 seconds in the dry side and 325 seconds in the moist side. Each went only to the entrance for dry air. Mixing of the two air currents in the downwind end of the apparatus caused a fairly large proportion to enter the "moist" side of the chamber initially, as in the first test. Starvation for 24 hours did not change the humidity preference if water was available, but caused the females to spend over 70 per cent of their time in the moist side of the olfactometer if water was lacking. This reversal of the humidity preference in *N. vitripennis* is similar to that recorded for *Blatta orientalis* L. (Orthoptera: Blattidae) by Gunn and Cosway (1938) and for *Tenebrio molitor* L. (Coleoptera: Tenebrionidae) by Dodds and Ewer (1952). There was no reversal for at least 48 hours if the parasites found puparia of *M. domestica*, probably because they imbibed some of the semi-liquid host contents.

The parasite's avoidance of damp habitats is important in relation to its ability to locate hosts because the puparia of many host species are in a drier habitat than that in which they have developed as larvae. This was the case in this study with *M. domestica*, the larvae of which matured in milk-soaked absorbent cotton and formed puparia in drier parts of the rearing jars. A similar observation with *M. domestica* was made by Hafez (1953). Larvae of several carrion-feeding species of Diptera crawl away from the corpse before they form puparia (Froggatt, 1915; Salt, 1932; Ullyett, 1949).

Discovery of Food

Food, apart from that obtained from the host, was not necessary for maturation of the parasite's eggs. However, females ate honey, jam, and sugar solutions in the laboratory, and some possibly find and ingest nectar, honey dew, or other foods on plants in nature. The extent to which olfactory, gustatory, and visual stimuli aid the females in finding these substances is unknown. Females that were either freshly emerged or were several days old and had attacked hosts lived longer if fed honey than if starved; therefore, natural foods may indirectly increase the parasite's chances of finding hosts by increasing her longevity. Furthermore, as shown by Edwards (1954b), mature eggs in female parasites that have already oviposited are resorbed more slowly if the females eat honey than if they are starved; therefore, the females probably have more mature eggs when they find hosts if they have fed meanwhile on nectar or other foods.

Discovery of Hosts

Finding the Host Environment

Many parasite species can perceive an environment in which their hosts often occur and, having found it, limit their activities mostly or entirely to this environment. Parasites usually perceive host-containing areas by either visual or chemical stimuli. The great variation in the physical characteristics of the host environments located by females of *N. vitripennis* rules out any possibility that they recognize them by sight; therefore, perception, if any, from a distance is probably by odour. This has already been investigated experimentally with carrion as the host environment, but with conflicting results. Laing (1937) concluded that females were attracted to stale meat that had not been infested by dipterous larvae, whereas Jacobi (1939) and Edwards (1954a) showed that only meat that had been infested influenced their movements. The last author also concluded that on a flat surface parasites made frequent sharp turns at the edge of, as well as within, an air stream contaminated by the

odour, and that these turns restricted their movements to the locality contaminated by the odour.

To investigate further the nature and effect of this olfactory stimulus, the behaviour of freshly emerged females was observed in the olfactometer by drawing the odour of different substances through one entrance (X or Y) and uncontaminated air through the other. The parasites always walked upwind to the entrance through which was drawn air that had passed over meat previously infested by either *C. vicina* or *P. lardaria* or over puparia of either species that had developed in meat. However, approximately equal numbers of parasites went to each entrance when the odour tested was one of: fresh, uninfested meat; uninfested meat that had been at 20°C. for six days or longer; puparia of *C. vicina* or *P. lardaria* that had been washed thoroughly as mature larvae to remove odour of the carrion; puparia of *M. domestica* that had developed in milk-soaked absorbent cotton; and milk-soaked absorbent cotton in which larvae of *M. domestica* or *P. lardaria* had fed. The parasites, as observed by Edwards (1954a), made frequent sharp turns at the limits of and within the area contaminated by the odour of meat previously infested by dipterous larvae. Hence they spent a large proportion of their time within this area, which comprised about one half of the total internal area of the olfactometer: four females tested for five minutes each stayed a total of 1,170 seconds in the contaminated and only 30 seconds in the uncontaminated air current. When the odour of each of the other substances was drawn through the apparatus, the females made few or no sharp turns and spent about half of their time in each air stream. Frequent turns, that kept the females in a favourable zone for finding hosts, are similar to those observed with the body louse, *Pediculus humanus humanus* L. (= *P. humanus corporis* DeG.) (Anoplura: Pediculidae), by Wigglesworth (1941) and with larvae of *M. domestica* by Hafez (1950). That the parasites were not attracted directly to the source of the odour was shown in another test, in which they remained distributed evenly throughout a closed glass dish that contained in one corner a piece of meat previously infested by larvae of *C. vicina*.

This behaviour therefore limits the movements of the females that encounter the odour of carrion to a more or less definite locality near the corpse, and therefore to a locality in which there are probably suitable hosts. How the female perceives the attractive odour was not investigated, though her antennae always point forward while she is walking and therefore probably are involved. Jacobi (1939) suggested that sense organs in the antennae and probably in the maxillary palps perceive olfactory stimuli from the host environment.

Though the attractive substance was not identified, its presence in maggot-infested meat and not in milk in which larvae of the same dipterous species had fed suggests that, when the host environment is a corpse, the attractive odour is that of either a decomposition product of the meat attacked by the larvae or of an excretory product of the larvae that have fed on meat. The same attractive substance may be produced in birds nests, where some nestlings often are killed by the dipterous larvae that feed on them. Whether odours of other substances in dung and rubbish aid the parasites in locating hosts in these habitats was not investigated.

Finding the Host Puparium

The ability of females of *N. vitripennis* to find puparia of a host species is closely related to the pupation habits of the host species. The puparia of those species that develop in carrion or dung are formed either in the host

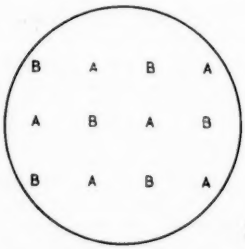

Fig. 2. Alternate arrangement of puparia of *M. domestica* in petri dish.

environment or in or on the ground at some distance from it; of those that mature on nestlings, usually within the nest. Many puparia in the ground are not found because the female parasites do not burrow into fine soil. As the ability of the females to find the host environment is affected by the odour of infested carrion that may adhere to the puparia, and as this attractive odour is removed if the larvae are washed before they pupate, part or all of the source of the odour may be removed from mature larvae that crawl over the ground for some distance, or the odour may be obscured if the puparia form in the soil. Olfactometer tests showed that females of *N. vitripennis* were not attracted by a distinctive odour of the puparia of either *C. vicina* or *P. lardaria* from which the source of the host environment odour has been removed. This result disagrees with that of Jacobi (1939), who concluded that the odour of the puparium is attractive to the parasites. Edwards (1954a) stated that the females can see puparia from a distance of less than five millimetres in bright light. This was confirmed experimentally, but the significance of the optical sense in finding hosts is probably limited by the occurrence of many puparia in the soil or in other protected habitats. Usually a puparium was found after the parasite's antennae touched it. The stimulus by which the female recognizes the puparium may be gustatory, though the humidity of the puparium is also important because the female rejects both very damp puparia and, as shown by Edwards (1954a), very dry ones without further examination.

Finding the Host Pupa

The female parasite climbs onto a puparium, which she has accepted for further investigation after a brief examination with the antennae, and walks slowly over the exposed surface for a minute or less while tapping it continually with the antennae. She rejects a puparium if, while walking on it, she finds the emergence hole of a fly or parasite; in this case she taps the edge of the hole for half a minute or more with the antennae before she leaves the puparium.

Experiments showed that the female parasite does not discriminate before drilling between puparia that she or other females have walked on and others that have not been examined. Six puparia of *M. domestica* 6.0±0.2 mm. long fastened in an upright position with smears of plasticine in a closed petri dish in the positions marked A (see Fig. 2) were left with 20 female parasites for three hours. Each puparium was drilled two or more times. The parasites were then removed, six puparia 6.0±0.2 mm. long that had not been examined previously were fastened in the positions marked B, and six females that had been standardized by the method of Edwards (1954a) and that would therefore usually readily parasitize hosts were admitted and left until each had had time to select a puparium and start to drill. The number of adult parasites on each group of puparia was then counted. Ten replicates were made; in these,

a total of 32 parasites selected puparia that had not been examined previously, and 28 selected puparia that had already been drilled.

The results indicate that previously examined puparia are often selected for drilling when others that have not been walked on are available. In most cases the puparium selected and drilled was the first that the female contacted. This behaviour of *N. vitripennis* therefore contrasts with that of females of *Trichogramma evanescens* Westw. (Hymenoptera: Trichogrammatidae), which usually reject before drilling hosts that have on their surface chemical traces left by the feet of females of the same parasite species (Salt, 1937).

Puparia that were mounted were, therefore, usually drilled if they had no emergence holes, and the female's ovipositor was inserted to its full length into the puparium. No eggs were laid inside freshly formed puparia in which pupation was not complete and, therefore, in which there was no space between the puparium and pupa, though the parasite fed after withdrawing her ovipositor; this feeding did not prevent further host development. Eggs were laid on living pupae and on pupae on which there were parasite eggs or first-instar larvae, and feeding followed; however, there was neither egg-laying nor feeding if the puparium contained a dead fly pupa or well-developed parasite larvae, pupae, or adults. The female's mouth parts were always moved vigorously for several seconds after the ovipositor entered a puparium that contained a living host that had not pupated, or after it pierced a pupa on which she later laid, but not after it entered a puparium whose contents were neither imbibed nor laid on. This behaviour corresponds to proboscis extension by adults of several dipterous species after sugar solutions were applied to hairs that acted as chemoreceptors on their legs (Dethier, 1955). It is therefore probable that the sense organs on the ovipositor of *N. vitripennis,* described by Edwards (1954a), are chemoreceptors and that they enable the female to discriminate between pupae that are suitable or unsuitable for the development of progeny. Sense organs that probably are chemoreceptors were observed or described on the ovipositors of other species of hymenopterous parasites by Fulton (1933), Varley (1941), and Dethier (1947).

Effect of Host Size

The size limits of the hosts parasitized by *N. vitripennis* were not determined; experimentally, puparia both of *C. vicina* that were over 10 mm. long and of *M. domestica* that were only 4.2 mm. long were accepted. Host size affects host finding in two ways: by influencing the probability of an accidental contact between the puparium and the female parasite, and by affecting the distribution of the parasite's eggs.

Probability of Finding the Puparium

Because a puparium is usually not perceived until the female's antennae touch it, a large puparium is more easily found than a small one in the same environment if they are equally uncovered. This was confirmed experimentally. Six large and six small puparia of *M. domestica* (6.0 ± 0.2 mm. and 5.0 ± 0.2 mm. long, respectively) were placed alternately in a closed glass dish two centimetres apart from one another, and six standardized female parasites were placed in the dish. The parasites were removed two hours later, after each had had time to attack only one host. The puparia were then dissected and the number of each size that had been parasitized was recorded. The experiment was repeated five times in light and five times in darkness with different hosts and parasites in each test. A total of 14 large and 6 small in light, and 15 large and 6 small puparia in darkness were parasitized; these included several large and small hosts that were drilled simultaneously by two parasites. The results show that

both in light and in darkness more large than small puparia were parasitized. Small host were, however, accepted when large puparia that had not been attacked were available. This suggested that the smaller hosts were accepted for parasitization as readily as the larger after they had been contacted. To investigate this, six large (6.0 ± 0.2 mm.) and six small (5.0 ± 0.2 mm.) puparia were set up alternately as in Fig. 2 and one standardized female parasite was placed in the dish and observed until she started to drill. Ten replicates with different hosts and parasites were made in light at 20°C.; a total of three large and four small hosts were mounted and left without being drilled. In a second series of 10 replicates with large puparia only, a total of eight puparia were mounted and left, whereas in a similar series of small puparia only three were mounted and left. Each parasite did not drum while passing over the puparia. This temporary failure to recognize puparia was also observed whenever a parasite was admitted to a dish that contained suitable hosts, and the first puparium drilled was apparently the first one that the parasite contacted after she had settled down in the dish. This does not, therefore, support the conclusion of Edwards (1954a) that relatively more small than large puparia are rejected after contact. It is, therefore, probable that the more frequent parasitization in laboratory tests of *C. vicina* than of *M. domestica* by *N. vitripennis*, recorded by Smirnov and Kuzina (1933), can be explained on the basis of host finding and not of host selection. This conclusion contrasts with that reached by Salt (1935) with regard to *T. evanescens* whose selection of hosts is regulated mainly by the host size.

Distribution of the Parasite's Eggs

Smirnov and Kuzina (1933) and Van der Merwe (1943) observed that, usually, more parasites matured in a large than in a small puparium. This is partly because, when there is superparasitism, starvation of the immature larvae limits at a lower level the number that mature in small hosts. In addition, large hosts are parasitized more frequently than smaller ones because they are found more easily, and because a parasite accepts and attacks a host that she or another female has recently parasitized. As suggested by Edwards (1954a) it is possible also that the number of eggs laid by a parasite during one period spent with a host depends to some extent on the size of the host. This possibility was investigated experimentally with 20 standardized parasites and 10 puparia of *M. domestica* of each of two lengths (6.0 ± 0.2 mm. and 5.0 ± 0.2 mm.). The behaviour of each female was studied from the time it contacted a puparium until it left it. The time spent with the hosts varied considerably and ranged up to 9½ hours. Each parasite drilled five times or less during the period and remained motionless on or within a few millimetres of the puparium between successive attacks. An attempt was made to count the parasite eggs on each pupa, but this was difficult and the results were probably inaccurate; therefore, because parasite egg mortality usually is negligible (Van der Merwe, 1943), the first-instar larvae were counted 72 hours after parasitization was completed. The larger puparia contained from 17 to 22 parasites and the smaller from seven to 11. Females of *N. vitripennis* therefore regulate the number of eggs laid during one period with a host in proportion to the size of the host. It is not known how this regulation is accomplished or whether it occurs when the puparium is partly buried or otherwise concealed, as is often the case with some hosts in nature. The significance of the regulation, insofar as searching for hosts is concerned, is that the proportion of the female's eggs laid in each host and, therefore, the proportion of her time spent finding puparia, is inversely related to the size of the host. However, the fact that, theoretically, a parasite

spends less time with each host if the latter is small does not necessarily mean that the incidence of parasitism in field populations is inversely related to host size, because large puparia are more easily located than smaller ones if other factors that influence host finding are equal.

Effect of Host Population Density

Some of the species attacked by *N. vitripennis* pupate almost exclusively on the remains of the corpse on which they have fed, and therefore are often heavily parasitized because the puparia are usually partially or completely uncovered and are in a relatively limited locality where they are more easily located. This explains why Ullyett (1949) recorded a higher percentage of parasitism in field populations of *Chrysomyia chloropyga* Wied. and *Chrysomyia albiceps* Wied. (Diptera: Calliphoridae) that pupated in or near a corpse than in those of *Phaenicia sericata* (Meig.) (Diptera: Calliphoridae), the larvae of which crawled away and entered the soil. In addition, relatively more hosts are parasitized in areas of very high host population density because the females often spend less time parasitizing each host. This results from the fact that a parasite usually rests near a puparium between successive attacks on it; therefore, if the distance between puparia is small, the female often mounts and parasitizes a second host after only one or two attacks on the first host instead of the usual three or more. This was confirmed experimentally: standardized parasites were confined singly at 25°C. for 24 hours in a petri dish 9.5 cm. in diameter that contained nine puparia of *M. domestica*, each 6.0 ± 0.2 mm. long, in a square so that adjacent puparia were either two centimetres or three millimetres apart. Five replicates each with a different female were done at each host population density. Two or three hosts were parasitized when they were two centimetres apart, and from three to five when they were three millimetres apart; however, the total number of eggs laid in each dish was not affected by the distance between the hosts. The significance of this phenomenon from the standpoint of host finding is that more puparia are found and parasitized at high host population densities because of a feature of the species' oviposition behaviour and not of its behaviour before it encounters puparia. It may partially explain the high incidence of parasitism, recorded by Whitehead (1933), of dipterous puparia by *N. vitripennis* in a bird's nest where the hosts were concentrated in a limited space. Another example of non-random spatial distribution of parasitism recorded by Varley (1941) with *Eurytoma curta* Walk. (Hymenoptera: Eurytomidae) probably resulted only from movements of the parasite after it had left the host.

Parasite Behaviour after Leaving a Host

The behaviour of a female of *N. vitripennis* after it left a puparium was the same as that before it had found the puparium: that is, it travelled in a fairly straight line on a flat surface if there was no odour of infested carrion, and made many sharp turns if this odour was present. Behaviour changes have been reported both for parasites after they leave hosts and for predators after feeding. Laing (1937) showed that females of *T. evanescens* that had travelled in fairly straight lines before they found hosts made many short-radius turns after they left them, and Fleschner (1950) and Putman (1955) showed that predacious species from several families followed unusually twisting paths after feeding. Because of this changed behaviour, the parasite or predator investigates thoroughly the area near the first host or prey; therefore, this behaviour is especially useful to parasites that discriminate between healthy and parasitized hosts and attack hosts that are sessile and are often grouped closely together, as with eggs of some of the species parasitized by *T. evanescens*, and also to predators whose prey are

similarly closely arranged. However, it would probably not help *N. vitripennis* find hosts because the latter are sometimes widely separated, and because parasitized hosts likely would be found and superparasitized. A change in behaviour similar to that observed with *T. evanescens* would result in an uneven spatial distribution of parasitism in nature, as was recorded by Varley (1941).

Discussion

The host-finding ability of the females of a parasite species mostly determines the capacity of the species to influence the population density of its host. Females of *N. vitripennis*, like those of many parasitic hymenopterous species, are not attracted from a distance directly to hosts but to an environment that usually contains suitable hosts, and further movements of the females are limited to this environment and are random with regard to individual puparia within it until the puparia are seen or are contacted with the antennae. The efficiency of this method of host finding depends on whether the hosts pupate within the host environment and, if so, on their population density and accessibility. Therefore, a large proportion of the puparia in birds' nests may be parasitized (Whitehead, 1933), probably because they are not buried and are in a limited habitat. However, hosts that pupate in the soil or outside the environment in which they developed are mostly immune to attack. This is why incidence of natural parasitism of *P. sericata*, one of the most destructive blow flies of sheep in South Africa, is usually very low and that of other, economically less-important species that pupate in the carrion is much higher, though puparia of *P. sericata* are more readily accepted in the laboratory (Ullyett, 1949). For the same reason *N. vitripennis* did not provide economic control of sheep blow flies either in Australia (Johnson and Tiegs, 1922) or in New Zealand (Miller, 1927). The capacity of each parasite to locate suitable hosts is further limited in all habitats by her inability to recognize puparia that she or other females have previously walked on and parasitized, and that she often rejects for oviposition only after drilling. This inability to discriminate between puparia that contain suitable hosts and those that do not results in a considerable loss of time by each female parasite because she may spend over half an hour drilling into a puparium of *M. domestica* and probably longer with larger puparia. This loss of time, as shown by Edwards (1954b), increases resorption of mature eggs in her ovaries and thereby decreases the number of eggs she can lay immediately after she finds a suitable host.

Flanders (1947) discussed morphological, physiological, and behaviouristic attributes that affect the capacity of parasitic Hymenoptera to find hosts. The results of the present study show how lack of two of these attributes, ability to avoid wasting time with unsuitable oviposition sites and ability to occupy all host-inhabited areas, limits the potential value of *N. vitripennis* as a biological control agent.

Summary

Females of *Nasonia vitripennis* (Walk.), (Hymenoptera: Pteromalidae) which parasitize pupae of numerous dipterous species that develop as larvae in carrion, dung, rubbish heaps, and on the young nestlings in birds' nests, usually avoided localities where the relative humidity of the air was more than 50 per cent, and thereby avoided habitats in which there were few suitable hosts. Though they were not attracted directly to the source of the odour of carrion, they reacted by searching for host puparia only in the area contaminated by this odour. The female's movements with regard to individual host puparia inside this environment were random, and she apparently recognized them by touch. She examined but did not drill puparia that had an emergence hole of a fly or of

parasites; otherwise, she usually drilled but laid no eggs if the host had not pupated or was dead, or if the puparium contained late-instar parasite larvae, pupae, or adults. Within certain limits at least, size of the puparium did not affect its acceptability to the parasite, but fewer eggs were laid on small pupae than on large ones by a female during one attack. The female's inability to burrow into the ground, where many of its potential hosts occur, and to avoid wasting time with unsuitable hosts seriously limits the efficiency of the species as a biological control agent.

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Notes on a Rare Fly, *Megagrapha pubescens* (Loew) (Diptera: Empididae)[1]

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The genus *Megagrapha* Melander is characterized by small size, pubescent eyes, broad thorax, large flattened scutellum, and broad wings. The wing venation is most distinctive, the basal cells being large and subequal, the crossveins confluent, the anal crossvein absent, and the anal vein curving along the caudal margin of the wing. The only other genus with these characteristics is the South American genus *Austrodromia* Collin, but in that genus the crossveins are distinctly basad of the apex of the subcostal vein, whereas in *Megagrapha* they are approximately opposite the apex.

Megagrapha was erected by Melander in 1925 for *Drapetis pubescens* Loew (1862), which was known from four female specimens, two from New York, one from Georgia, and one from Massachussetts. The species has not since been mentioned in the literature, and no other species have been referred to the genus. However, recent examination of material in the U.S. National Museum revealed that Malloch had described the male from Maryland in 1923 under the name *Coloboneura exquisita.* Except for inclusion in keys and catalogues, there are no further records of this species.

The author collected one male and three females in second growth maple woods in southcentral Ontario in 1955, and a male and a female in a similar habitat in North Carolina in 1957. The same year (1957), Dr. J. R. Vockeroth, Entomology Division, Ottawa, collected one male and three females in North

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Carolina at light during a heavy rain, and a female with a sweep net at Ottawa, Ontario. These specimens, along with one female from Laniel, Quebec, brought the total number of specimens in the Canadian National Collection to three males and nine females. In the U.S. National Museum there are 10 males and four females from Virginia and Maryland and one male from Edmonton, Alberta.

***Megagrapha pubescens* (Loew)**

Drapetis pubescens Loew, 1862, Berl. Ent. Zeitschr. 6: 201.
Melander, 1902, Trans. Am. Ent. Soc. 28: 210, 340.
Megagrapha pubescens, Melander, 1925, Gen. Insect., Fasc. 185: 301.
Coloboneura exquisita Malloch, 1923, Ent. News 34: 5 (new synonym). Melander, 1925, Gen. Insect., Fasc. 185: 294. Curran, 1931, Am. Mus. Novit. 467: 11.

The species is unusual in that there is sexual dimorphism of both the antennae and the wings. The male antenna (Fig. 4) has the second segment shorter and plumper than in the female, and the arista is about half as long and much thicker with a tuft of hairs at the apex. The male wing (Fig. 2) is distinctly shorter and stubbier, the basal cells broader and extending almost to the middle of the wing. It is strongly patterned, with moderate infuscation basally and costally, and with strikingly well-defined dark areas in the apical fourth of the second basal cell and in the posterior cells just beyond the posterior crossvein and along the fourth vein, whereas the female has only a trace of these markings. Also, the male thorax is conspicuously paler dorsally, and yellowish-brown as opposed to glossy black in the female.

Male

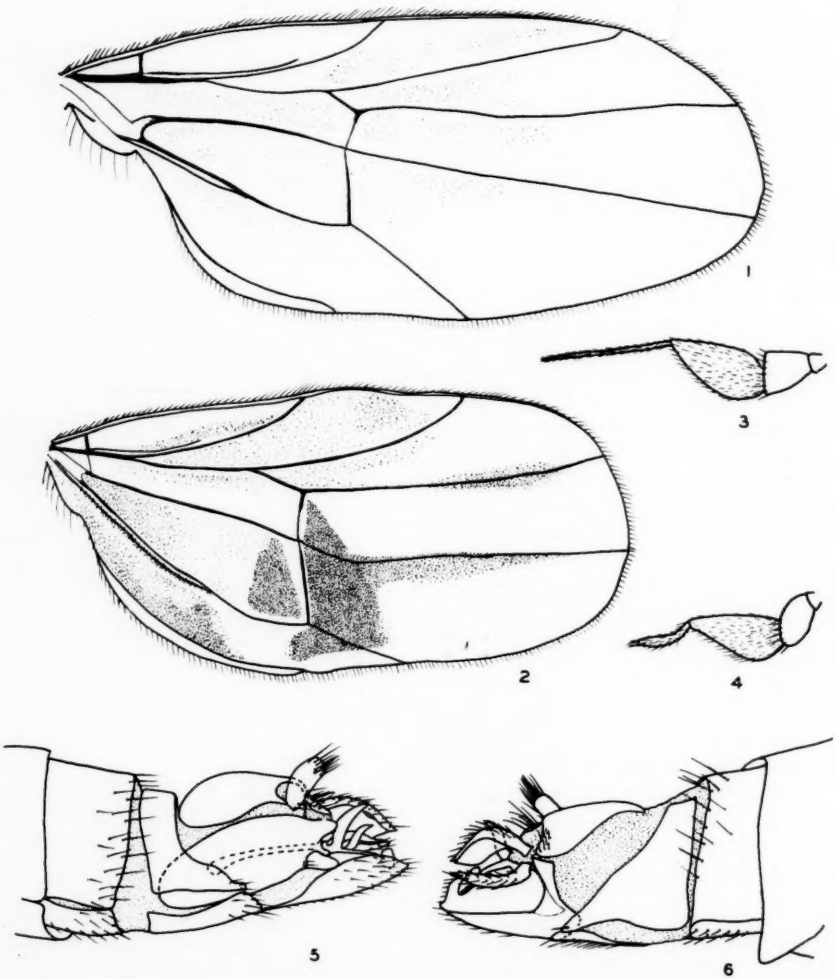
Length 1.9-2.2 mm. Head globular, black. Eyes distinctly pubescent; almost contiguous near antennae, with a small antennal excision; separated dorsally by ocellar triangle; posterior margin sinuate; facets uniform. Occiput covered evenly with pale yellow, hairlike bristles. Antenna (Fig. 4) dull yellow; first segment very small; second short, beadlike; third triangular, half as broad as long; arista pale, two-thirds as long as third segment, thick, with an apical tuft of hair. Palpus black, broadly oval, evenly pubescent. Proboscis vertical, thick, half as long as depth of head.

Thorax broad, short, the humeri scarcely evident; scutellum large, flat to slightly concave dorsally. Dorsum pale yellowish-brown, pleura dorsally concolorous with dorsum, ventrally straw-yellow. Scutellum medially dark brown, basal corners yellow. Haltere dull yellow. Squama basally black, apically yellow. Dorsum with an even vestiture of pale hairs, becoming bristlelike towards scutellum; one pair of black bristles just in front of basal angles of scutellum; laterally a series of three black notopleural bristles. Scutellum with a pair of yellow preapical bristles and two pairs of black marginal bristles. Pleura bare except for a small patch of pubescence on propleuron and on metapleuron in front of haltere.

Legs pale yellow, apical tarsal segments infuscated; evenly covered with moderate pale pubescence except for several weak bristles preapically on anteroventral surface of hind femur and 6-8 stronger bristles on apical half of posterodorsal surface of hind tibia. All femora short, slender; tibiae also unmodified, no apical spurs present.

Wing (Fig. 2) half as broad as long, apex broadly rounded, subtruncate. Stalk of second and third veins long, second vein strongly curved towards costa, third vein weakly curved costally. Basal cells extending almost to middle of wing; first truncate; second closed diagonally, with the posterior margin strongly bowed outwards. Fourth vein with a broadly rounded bend beyond basal cell; apical portion of fifth vein less than half as long as basal portion; a

distinct spurious vein evident just posterior to and parallelling basal third of fifth vein. Anal vein coincident with posterior margin of wing on its basal third, then bending inwardly and parallelling posterior margin, ending in wing margin opposite apex of second basal cell. No anal crossvein present. A distinct triangular black spot in apical third of second basal cell, and a larger, transverse triangular black spot just apicad of crossveins, broadest just behind apex of second basal cell. Apical portion of fourth vein broadly infuscated for most of its length, medial part of the apical portion of third vein infuscated. Basal and costal portions of wing lightly infuscated. Costal bristle absent, but marginal cilia long basally.



Figs. 1-6. *Megagrapha pubescens*. 1-2, Wings; 1, female; 2, male. 3-4, Antennae, lateral view; 3, female; 4, male. 5-6, Hypopygium and adjacent sclerites, lateral view; 5, left side; 6, right side.

Abdomen short, broadly conical, consisting of seven segments and the elongate hypopygium. Abdomen, including hypopygium, black. Pubescence black, short dorsally, longer and more bristlelike on lateral margins. Hypopygium (Figs. 5, 6) twisted almost 90° to the right, the parts distinctly asymmetrical.

Female

Differing from the male as follows:

Head with occipital hairs dark brown to black. Antenna (Fig. 3) with basal segments yellow; third segment and arista dark brown; arista slender, densely pubescent, almost twice as long as third segment.

Thorax with dorsum (including scutellum) subshining black, dorsal portions of pleurae heavily infuscated. Knob of haltere black, stem yellow. Squama black. Thoracic bristles yellow to dark brown, notopleural bristles variable from four to six on each side.

Wing (Fig. 1) longer and more slender than in male, the second basal cell smaller. Wing markings only faintly visible as light infuscations in central portions of cells on basal two-thirds of wing.

Abdomen black, subshining, consisting of seven main segments and two segments forming a slender, glossy ovipositor. Pubescence brown, uniformly short.

Specimens Examined:—In Canadian National Collection, 13 ♂♂, 9 ♀♀ as follows:—ONTARIO: Penetang, 1 ♂, 1.VIII.1955, 2 ♀♀, 21.VIII.1955 (J. G. Chillcott); Midland, 1 ♀, 20.VIII.1955 (J. G. Chillcott); Ottawa, 1 ♀, 29.VII.1957 (J. R. Vockeroth). QUEBEC: Laniel, 1 ♀, Cage #84, 20.VIII.1933. NORTH CAROLINA: Highlands (3,800 ft.) 1 ♂, 1 ♀, 4.VI.1957, 1 ♀, 29.V.1957, 1 ♀, 20.VI.1957 (J. R. Vockeroth), 1 ♀, 15.VII.1957 (J. G. Chillcott); Cashiers, 11 miles east (4,000 ft.), 1 ♂, 12.VII.1957 (J. G. Chillcott).

In U.S. National Museum, 11 ♂♂, 4 ♀♀, as follows: MARYLAND: Glen Echo, 1 ♂ (holotype of *C. exquisita*), 21.VIII.1921, 1 ♂, 11.VI.1922, 1 ♂, 22.V.1922, 1 ♂, 26.V.1923, 1 ♀, 10.VI.1923 (J. R. Malloch); Cabin John, 1 ♂, 4.VI.1916 (R. G. Shannon); Plummers Island, 1 ♀, 24.VII.1903 (W. V. Warner). VIRGINIA: Chain Bridge, 1 ♂, 20.VII.1922 (J. R. Malloch); Mt. Solon, Augusta Co., 2 ♂♂, 24.VI.1951 (W. W. Wirth); Alexandria, 1 ♂, 1 ♀, 2.VI.1951, 1 ♀, 17.VI.1951 (W. W. Wirth); Maywood, Alexandria Co., 1 ♂, 14.V.1922 (W. L. MacAtee). ALBERTA: Edmonton, 1 ♂, Lot 301, 1932 (Owen Bryant).

Summary

Both sexes of *Megagrapha pubescens* (Loew) are redescribed, and wings, antennae and male hypopygium are figured. *Coloboneura exquisita* Malloch is reduced to synonomy. Distributional records are brought up to date, with notes on adult habitats.

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B & Z Library

Two Quantitative Methods for Measuring Insect Activity[1]

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Various methods for recording the activity of insects have been reported (e.g. Park, 1935, 1937; Gunn, 1940; Hammond, 1953). In this type of investigation, three characteristics are desired in the method: a) the apparatus should be sufficiently sensitive for recording small movements in small insects; b) the portion of the apparatus in immediate contact with the insect should permit easy subjection of the organism to various environmental conditions; c) the apparatus should permit rapid and easy accumulation of data from a number of insects. Two methods have been developed in the present laboratory in attempts to meet as far as possible these desirable qualifications.

Methods and Results

Discontinuous Soot-Tracing Method

This method is based upon the quantitative photometric measurement of marks made by the legs of an insect moving on a soot-blackened layer on the inner surface of a petri dish. The apparatus (Fig. 1) was found to be satisfactory for studies with the scolytid beetles *Trypodendron lineatum* (Oliv.) and *Hylurgops sp.* In Fig. 1, *a* shows the soot-blackened petri-dish bottom. Fig. 1, *b* shows the details of a screen-wire disc, which fits into the dish bottom, to which a strip of photographic film has been fastened to form a "wall". A small iron bar is maintained in the top centre of the assembly by a piece of wire stretched across it. The lid of the petri dish is shown in Fig. 1, *c* with a small magnet held in place on top by means of a piece of wire stretched across the lid. Fig. 1, *d* illustrates the completely assembled apparatus, with the screen-wire assembly resting on the blackened bottom of the petri dish. The screen disc serves both in allowing placement of the insect onto the blackened surface without direct handling, and in providing a substrate for the organism to cling to.

The experimental procedure involving this apparatus was standardized. After lightly blackening the inner surface of the dish, its transparency to light is measured by means of a specially constructed densitometer. An insect to be tested is put onto the screen (Fig. 1, *b*). When the insect has become quiescent, the lid (*c*) is put over the screen assembly, the magnet holding the two parts together, with the insect inside. By means of the lid, the screen assembly is then lowered gently onto the blackened surface. After a predetermined time interval, during which the insect's legs mark the blackened surface (Fig. 1, *e*), the screen assembly is carefully removed and the transparency of the blackened bottom again determined. With practice, the screen assembly may be added once to the blackened surface and removed without appreciably marking the latter.

The difference between the two transparency readings is related to the amount of moving (e.g. walking) done by the insect. It is important, however, that the activity interval be as short as possible, to prevent "overlapping" of the marks, and therefore an erroneous transparency-difference reading. The best results are obtained with the least amount of "overlapping".

Some figures ("activity indices") obtained using three adult *Hylurgops* (length 5 mm.) in this apparatus at two different temperatures are given in Table I. For each "time interval" the insect was put onto a new blackened surface. The activity time interval was 30 minutes, following a preliminary period during

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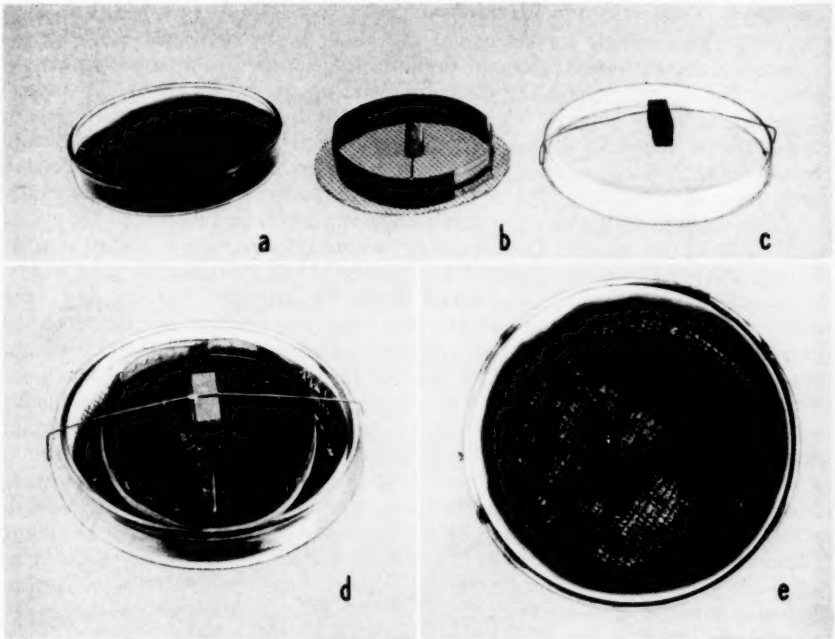


Fig. 1. Soot-tracing apparatus. (a) blackened dish bottom; (b) screenwire assembly; (c) glass lid with magnet; (d) assembled unit; (e) marks made by *Trypodendron* in 20 minutes at 24°C.

which the insect became quiescent. The activity index was obtained from the light-density difference in foot-candles per hour in each case. There is a definite trend toward a higher index in the runs at the higher temperature. In a series of five tests, in which the experimental procedure was the same but with the insects omitted, there was no noticeable difference between transparency readings taken before and after each run.

TABLE I

Activity indices (foot-candles per hour) for two adult *Hylurgops* at 24° C. and one at 28° C. determined with the soot-tracing method (time interval 30 minutes)

Time interval	Insect 1 (24°)	Insect 2 (24°)	Insect 3 (28°)
1	0.72	0.62	1.26
2	0.24	0.44	1.26
3	0.22	0.12	1.24
4	0.42	0.38	0.70
5	0.38	0.38	2.08
6			0.96

Continuous Variable-Resistance Method

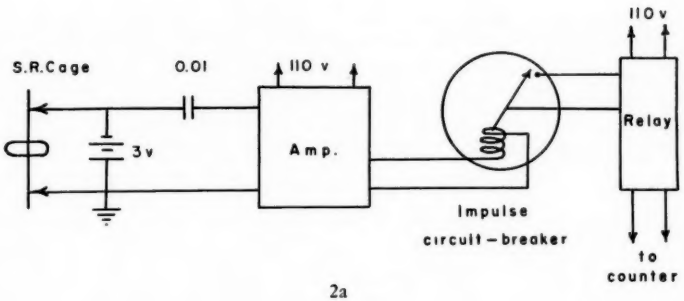
With this method, movements of the insect are transformed into changes in electrical current which, through amplification, are used to activate a counting device. Fig. 2, *a* illustrates the electrical hook-up of the apparatus. A swinging-resistance cage (Fig. 2, *b*) was constructed by fastening a small gelatin capsule to the centre of a piece of automatic-pencil graphite, the whole resting across two razor-blade edges. The "resting resistance" between the two blades varies from time to time, but is usually of the order of 2000 to 3000 ohms. Small movements of the gelatin-capsule cage can result in resistance changes of as much as 10,000 ohms. This assembly is connected, across a 3-volt battery, through a capacitor, to the input of a phono-amplifier ("Heathkit", four stage). An impulse circuit-breaker, connected across the amplifier output, is a very sensitive relay and serves to convert the electrical energy of the amplified current changes into mechanical energy with which to open the primary circuit of an electronic relay. The circuit breaker in the present apparatus was constructed from an old milliammeter; however, a commercial product is available. An electronic relay is connected across the "switch" portion of the circuit breaker. With a current change in the amplifier input resulting in an opening of the primary circuit, the best results have been obtained using the "normally closed" secondary circuit of the electronic relay. An automatic electric calculator is plugged into the secondary circuit of the electronic relay. With the "addition" key of the former fastened down, the apparatus can be allowed to run for as long a time as necessary, the calculator increasing its sum at a constant rate during the intervals when an electrical current change maintains open the primary circuit of the electronic relay. A standard counter which operates only upon a make or break of the circuit is not adequate in this case. Proper grounding and screening of the apparatus is essential, as well as elimination of feed-back from the calculator.

When the insect to be tested has become relatively quiescent in the swinging resistance cage, the gain of the amplifier is adjusted to give a threshold adequate to respond to the electrical current changes. Any values on the calculator are nullified. The experiment is begun by noting the time and locking down the "addition" key of the calculator. The value on the calculator is allowed to increase for a predetermined time.

TABLE II

Summated counts for 30 minute runs during one day for one adult *Trypodendron* determined with the variable-resistance method

Time interval	Calculator counts	Counts per minute
9:55 – 10:25	4302	143.4
10:30 – 11:00	4812	160.4
11:10 – 11:40	4337	144.6
11:45 – 12:15	4787	159.6
13:05 – 13:35	5480	152.7
13:50 – 14:20	4796	159.9
15:01 – 15:31	3872	129.1
15:45 – 16:15	2488	82.9



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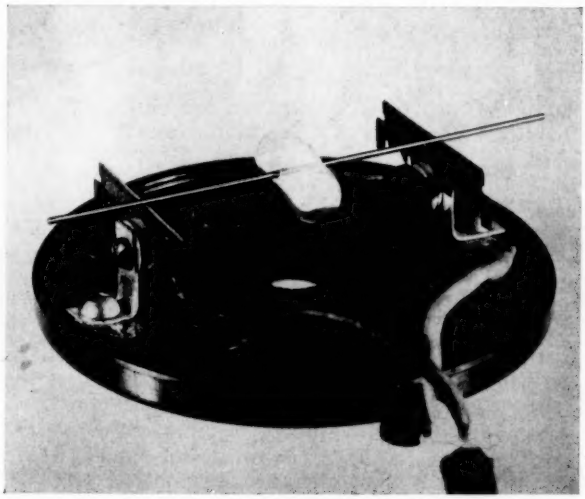

2b

Fig. 2. Variable-resistance apparatus. (a) wiring diagram; (b) swinging resistance cage assembly.

The results from a series of runs during one day, using the above method, with the ambrosia beetle *Trypodendron* are given in Table II. Thirty-minute runs were made at different intervals throughout the day. During most of the day the activity of the insect was fairly constant, falling off toward the end of the experiment.

Discussion

Some advantages in using the soot-tracing method are: a) the data may be replicated quickly; b) the dishes may be put into a variety of environmental conditions; and c) the method is simple and inexpensive. Two sources for difficulty with this technique are: a) allowing too long an activity interval, resulting in excessive "overlapping"; and b) with very small insects (e.g. *T. lineatum*) slight irregularities between the screen disc and blackened surface assume critical importance. Some experiments have shown that the soot-tracing method would be useful for studies with lepidopterous larvae and adults.

Some advantage in using the variable-resistance technique are: a) a record of insect activity may be made continuously over long time intervals; and b) with a minimum of modification the small cage assembly may be placed in a variety of environmental conditions with ease. The apparatus merely provides, however, an *index* of the activity of the insect, which may be compared with a similar index obtained under comparable conditions using the same resistance cage.

Summary

Two quantitative methods for obtaining indices of insect activity have been described. One method involves the photometric measurement of marks made by an insect moving on a soot-blackened layer of glass. In the second method, insect movements are converted into changing electrical currents; the latter are automatically summated. With both methods it should be possible, with a minimum of modification, to obtain activity data for insects in a variety of environmental conditions without appreciably affecting the efficiency of the recording apparatus.

Acknowledgments

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A Controlled-Interval Light Trap for Microlepidoptera[1]

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Although many traps have been designed to study the responses of Lepidoptera to light sources of various intensities and qualities (Gui *et al.*, 1942; Taylor and Deay, 1950; Glick and Hollingsworth, 1954; Merkl and Pfrimmer, 1955; Frost, 1957), few have been designed for studies of flight periodicity. The first one designed for the latter purpose was described by Seamans and Gray (1934). It consisted of seven individual collecting units built into one structure, each unit being operated for one hour of the night. Interval light traps subsequently designed by Hutchins (1940), Nagel and Granovsky (1947), and Coon (Frost, 1952) are of the Minnesota type (Frost, 1952), having a lamp bulb, hood, baffle and funnel. Beneath the funnel is a turntable, which brings a series of collecting jars under the spout of the funnel at regulated intervals. The Rothamstead trap (Williams, 1935, 1948) is also based on a bottle-changing mechanism.

The foregoing traps have all met with noteworthy success in captures of the macrolepidoptera. However, the numbers of microlepidoptera taken in these traps have been relatively low, differences in flight habits between the two groups being important. In general, the large, heavy-bodied, strong-flying moths of the former group fly directly to the source of the light. Stunned by collision with a bulb or a baffle or overcome by heat, they fall and are trapped in the collecting jars. Microlepidoptera, on the other hand, do not normally approach the light closely. They tend to remain at a slight distance from the source of light, periodically flying in wide circles about it. Consequently, they are captured only when they approach so close to the lamp that they are overcome by heat or the vapours of the toxicant in the collecting jars. This paper describes a trap that was designed to take microlepidoptera at controlled intervals. It was developed during studies of the flight behaviour of the diamondback moth, *Plutella maculipennis* (Curt.) (Harcourt, 1957).

Design

The trap (Fig. 1) is described in three main sections: the trapping unit, the collecting cartridge, and the disc-release mechanism. The trapping unit attracts and retains the insects, the collecting cartridge apportions the catch by means of sweep discs, and the disc-release mechanism controls the dropping of the discs.

Trapping Unit

Preliminary studies at Ottawa in 1951 confirmed the observation by Frost (1949) that certain microlepidoptera, including the diamondback moth, could be readily taken in a New Jersey mosquito light trap (Mulhern, 1942). Compared with a Minnesota trap, this trap captured more of several species of microlepidoptera, and at least ten times as many of the diamondback moth. Accordingly, certain features of the trapping unit of the present device are patterned after the New Jersey trap.

The trapping unit consists of a vertical aluminum cylinder 10 inches in diameter by 12 inches, with an aluminum hood 16 inches in diameter. The clearance between the cylinder and the hood is 1½ inches. The source of light, a 100-watt inside-frosted incandescent lamp bulb, is suspended from the

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the top of the inside of the hood so that the centre of the bulb lies in the clear area between the cylinder and hood. Just below the bulb, at the upper end of the cylinder, is an eight-inch fan that produces a down-draft of about 200 cubic feet of air per minute. The fan is so attached that the blades are in a horizontal plane. The fan motor (1/150 H.P.; General Electric, New York, N.Y.) is mounted at three points in the centre of the cylinder. Hardware cloth of ¼-inch mesh is stretched from the top of the cylinder to a position just inside the hood. This excludes macrolepidoptera and other large night-flying insects.

The funnel is of light-gauge sheet aluminum. It is wrapped about the periphery of the cylinder at its base and held in position by two spring hooks. The operator folds it back while servicing the trap. At the apex of the funnel is the funnel ring, a ring-shaped aluminum casting on which the collecting cartridge is mounted.

Collecting Cartridge

The catch is apportioned by sweep discs that are released at predetermined intervals from a supply held in a stacking tube at the uppermost end of the cartridge. The discs slide down an axial guide rod into a collecting tube. In falling, they sweep the sides of the tube, trapping any insects that may attempt to crawl back up. The disc method of apportioning the catch was used in the aphid trap of Johnson (1950).

The top of the collecting cartridge consists of a four-inch disc of cast aluminum drilled centrally to receive the upper end of the guide rod. Four ¼-inch steel rods extend from the periphery of the disc to a ringlike aluminum casting at the other end of the cartridge. These rods give the cartridge considerably rigidity. Further strength is added by aluminum support rings in the control area. The stacking tube, a 3½-inch-x-7-inch cylinder of light-gauge sheet aluminum, extends from the upper end of the cartridge to the first support ring. The collecting tube, a 3-inch-x-11-inch cylinder, extends from the lower end of the cartridge to the attachment ring. It is made of .018 gauge zinc with round perforations .055 inches in diameter (B. Greening Co. Ltd., Hamilton, Ont.). Air that is compressed as a disc falls is thus allowed to escape at the sides of the tube. The collecting cartridge is attached to the funnel ring by two brass machine screws with gnarled heads. A ¼-inch brass rod with a projecting arm holds the discs within the stacking tube while the disc-release mechanism is being set in place.

Guide Rod.—The guide rod is of ½-inch Monel (The International Nickel Co. of Canada Ltd., Copper Cliff, Ont.), which was chosen after a great deal of experimentation. Fumes of hydrogen cyanide quickly corroded rods of steel, copper, and brass, impairing the sliding action of the discs. Rods of inert plastic were insufficiently rigid; even a slight amount of play in the rod caused the discs to jam. The guide rod is held in position by a centring plate at the bottom of the cartridge. The centring plate is an aluminum disc that fits snugly under the lower support ring. It is drilled centrally to receive the threaded end of the guide rod and is fastened securely over the lower support ring by means of a brass thumbscrew. Minute holes in the centring plate allow air to be forced out when the first disc falls.

Sweep Discs.—The discs, which weigh 23 grams, fit snugly in the walls of the collecting tube. They were machined from a 2¾-inch rod of acrylic plastic (Crystalx Corp., Lenni Mills, Pa.). Each disc (Fig. 2) has a central collar ½ inch high and ¾ inch in diameter through which there is a hole ½ inch in diameter. The tolerance between discs and guide rod is minimal to

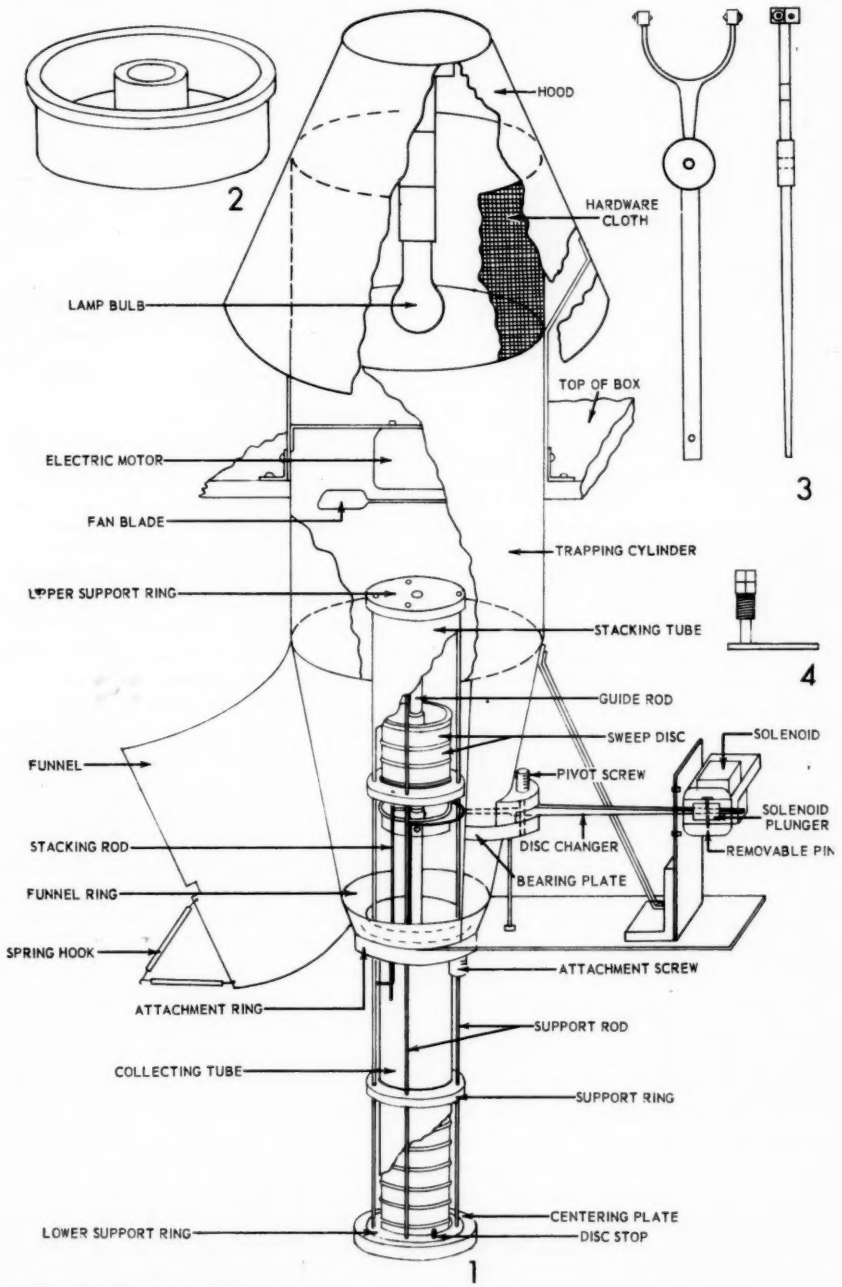

Fig. 1. Diagram of light trap.
Fig. 2. Sweep disc.
Fig. 3. Disc changer. Left, top view. Right, side view.
Fig. 4. Disc stop.

prevent even the slightest degree of tilting, which might cause the discs to pile up on the rod. The hole is of the same diameter as the Monel rod and is machined to a loose fit. The collar is not so high as the edge of the disc, the point of contact between discs being confined to a 2-mm. strip on the inside edge of the top of the rim, minimizing the crushing of specimens between discs. The floor of each disc contains a thin layer of potassium cyanide crystals, which act as the killing agent. The discs fit snugly together, forming an almost air-tight asphyxiation chamber between adjoining discs and preventing the insects from crawling from disc to disc.

Disc-release Mechanism

This comprises a disc changer, a solenoid and a timer. The disc changer (Fig. 3) is cast in bronze in the shape of a horseshoe with a long arm extending from the vertex. A slot in the funnel accommodates the arms of the disc changer. The changer pivots at its basal end between two aluminum bearing plates welded to the face of the funnel. The distal end of the disc changer is fastened to the solenoid plunger by means of a removable brass pin. The end of each arm of the changer is fitted with a tapered steel pin that projects inwardly. The arms are offset slightly in a vertical direction and the pile of discs rests on the two pins. The adjustment of the arm pins is critical.

The soleniod is 115-volt, 60-cycle, having a four-pound pull (Hammond Manufacturing Co., Ltd., Guelph, Ont). It is perhaps of greater capacity than necessary; however, it must be of sufficient strength to overcome the resistance of the changer arm and to snap the plunger into the solenoid when the circuit is opened. When the solenoid is activated, the disc changer is moved horizontally and a single disc is released. At this time the upper arm of the changer moves across, intercepting the next disc. When the circuit is broken, usually in a few seconds, a contraction-type coil spring pulls the arm back to its original position. The coil spring is adjusted by trial and error.

The timer consists of a cam-shaped disc of Plexiglass (Crystal Glass and Plastics Ltd., Toronto, Ont.) fitted to the adjustment knob of an ordinary alarm clock. The disc contains one or more contact points so that the time intervals may be varied. An electrical contact is made each time the minute hand of the clock reaches a chosen spot on the dial. This activates the solenoid mechanism and a disc is tripped. The timer and other electrical components of the trap are governed by a night switch (Paragon Electric Co., Two Rivers, Wisc.).

Operation and Maintenance

To remove the overnight catch for study, the pivot screw of the changer arm is removed, as is the pin connecting the distal end of the arm to the selonoid mechanism. The changer arm is then pulled from the funnel. The cartridge is freed from the funnel ring by removing the two attachment screws.

In the laboratory, the cartridge is mounted on a wooden stand, which leaves the operator free to work with both hands. The disc stop (Fig. 4) is then engaged and the centring plate removed by unscrewing the wing nut at the distal end of the guide rod, enabling the discs to be slipped from the guide rod. They may be removed for examination one at a time by use of the disc stop or they may all be removed at the same time and arranged in a series on the laboratory table.

After the discs have been emptied and brushed free from debris, they are slipped back onto the guide rod. The pile of discs is then pushed by means of a long stick into the stacking tube, where they are held by the projecting arm of

TABLE I

Numbers of insects of major orders taken in a light trap in various hours of the night of August 26–27, 1957, Ottawa, Ontario

Order	Main family	Hour of night*									
		1	2	3	4	5	6	7	8	9	Total
Diptera	Chironomidae	757	83	56	23	48	49	13	7	6	1042
Lepidoptera	Plutellidae	42	46	34	28	26	17	12	10	7	222
Hymenoptera	Ichneumonidae	4	3	8	4	4	3	8	10	11	55
Homoptera	Cicadellidae	15	7	5	2	0	7	0	0	0	36
Heteroptera	Miridae	5	0	3	17	5	2	0	0	0	32
Coleoptera	Staphylinidae	3	6	2	6	2	0	0	0	0	19
	Total	826	145	108	80	85	78	33	27	24	1406

*Beginning half an hour after sunset.

the stacking rod. The centring plate is now refastened, but not too tightly lest the guide rod bend. After the cartridge is remounted the arm of the stacking rod is swung away and the discs are allowed to come to rest on the disc changer. A spare cartridge obviates need for visiting the trap more than once daily.

Little care of the cartridge other than periodic replenishing of the cyanide is necessary. Liners of filter paper on the surface of the cyanide extend the life of the cyanide and prevent the moths from becoming entangled in the crystals. The guide rod and the inner surface of the collecting tube as well as the discs themselves should be cleaned periodically to remove debris and oxidate that may interfere with the sliding of the discs.

The electrical apparatus requires the usual degree of maintenance. Circuits should be inspected frequently lest shorting occur and for the same reason the contact knob at the back of the clock should be kept free from moisture. To reduce the corrosion in the moving parts of the apparatus and to provide shelter for the operator while changing the collecting cartridge, the trap was installed in an inverted wooden box, 4 feet x 4 feet x 4 feet, with a hinged lid. The trapping unit projects above the box from the mid-point of the cylinder. Enclosing the trap caused an air-block that reduced the amount of air moved by the fan to 100 cubic feet per minute[3]. Consequently, a blower (1/40 H.P. motor; Redmond Co. Inc., Owosso, Mich.) was attached to the bottom of the rear panel of the box and operated in conjunction with the trap fan, increasing the capacity to 450 cubic feet per minute.

Performance

During its five years of operation, 1953-1957, the trap has been highly effective for captures of the diamondback moth, the insect occasionally being taken in almost incredibly high numbers. For example, 454 moths were captured during the night of August 28-29, 1953, and 921 and 1,183 during the nights of August 19-20 and 21-22, 1955. Totals for August for 1953 to 1957 were as follows: 1953, 2,254; 1954, 628; 1955, 5,489; 1956, 571; 1957, 407.

[3]Determined by the method of Mulhern (1948).

Because the trap was operated near fields of vegetables, chiefly Cruciferae, where the diamondback moth was particularly abundant, other microlepidoptera were taken in relatively few numbers. Table I shows a typical night's capture of all insects taken, according to the major orders.

Summary

The design, operation, and performance of a light trap for capturing microlepidoptera at predetermined intervals are described. The moths are drawn by a fan into a collecting cartridge, where they are apportioned by means of sweep discs. The discs contain crystals of potassium cyanide and fit snugly together, forming an asphyxiation chamber between adjoining discs. The discs are released by a tripping mechanism activated by a solenoid. The trap was operated successfully for five years. A typical night's capture is illustrated.

Acknowledgment

The authors are indebted to Mr. C. Jackson of the Entomology Engineering Shop, Entomology Laboratory, Ottawa, for help in designing and fabricating and for drawing the light trap herein described.

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Studies of the Byron Bog in Southwestern Ontario
IX. Insects Trapped as Adults Emerging from Redmond's Pond[1]

By W. W. JUDD[2]

Introduction

In the description of the Byron Bog (Judd, 1957a) it was pointed out that Redmond's Pond is situated in the northwest corner of the bog and that during 1956 a tent-trap was anchored in a small bay in the northeast corner of the pond to trap insects emerging as adults from the water. The position of the trap on the pond is shown in the map accompanying the description of the bog (Judd, 1957a) and the structure and use of the trap are also described by Judd (1957b). The trap was placed on the water on May 15, 1956 and remained there until November 8. It was about four feet from the edge of the pond in water about two feet deep. At this point the bottom of the pond was composed of a thick layer of loose, brown peat and the adjacent edge of the pond was occupied by a dense growth of leatherleaf, *Chamaedaphne calyculata*, growing in *Sphagnum* (Judd, 1957a). The branches of the bushes of leatherleaf extended out over the water of the small bay in which the trap floated. The only rooted plant growing in and around the trap was spatterdock, *Nuphar advena*. Floating in the water was a sparse growth of bladderwort, *Utricularia vulgaris*, and on the surface of the water there were a few scattered fronds of duckweed, *Lemna minor*, and water flax-seed, *Spirodela polyrhiza*.

On each day from May 15 to November 8 the insects were collected from the trap by methods described by Judd (1957b). The insects so collected were put into a poison jar and taken to the laboratory for sorting, counting, pinning (or preserving in fluid) and labelling. The following specialists in the taxonomy of the various groups of insects kindly identified the insects: F. P. Ide, University of Toronto (Ephemeroptera), E. M. Walker, Royal Ontario Museum, Toronto (Odonata), L. A. Kelton, Systematic Entomology, Department of Agriculture, Ottawa (Hemiptera), G. B. Wiggins, Royal Ontario Museum, Toronto (Trichoptera), E. G. Munroe, Systematic Entomology, Department of Agriculture, Ottawa (Lepidoptera), G. W. Byers, University of Kansas (Tipulidae), A. Stone, United States Department of Agriculture. Washington (*Chaoborus*), W. W. Wirth, United States Department of Agriculture, Washington (Tendipedidae), J. G. Chilcott, Systematic Entomology, Department of Agriculture, Ottawa (Psychodidae, Ephydridae), J. R. Vockeroth, Systematic Entomology, Department of Agriculture, Ottawa (Dolichopodidae), J. F. McAlpine, Systematic Entomology, Department of Agriculture, Ottawa (Drosophilidae). The mosquitoes were identified by the writer using keys in Matheson (1944) and Carpenter and LaCasse (1955).

All specimens are retained in the collection of the Department of Zoology, University of Western Ontario except as noted in the following account: United States National Museum (USNM) Royal Ontario Museum (ROM), University of Kansas (UK).

Account of the Insects Collected

Emerging insects were first caught in the trap on May 20, 1956 and the last insect was caught on October 6. The numbers of the several species of insects trapped are presented in Table I. The great majority were Diptera

[1]Contribution from the Department of Zoology, University of Western Ontario; a project supported by funds from the government of Ontario granted through the Ontario Research Foundation.

[2]Associate Professor of Zoology; the collections were made and the data assembled while the writer held a Summer Research Associateship of the National Research Council of Canada during 1956 and 1957.

(98.5%) and among the Diptera the midges, Tendipedidae, predominated (75.8%) followed, in point of numbers present, by the Culicidae (23.7%). The other orders were represented by only a few insects each. Three definite peaks of maximum abundance occurred through the season i.e. June 8 (37 insects), August 4 (30 insects) and August 28 (72 insects).

TABLE I

Number of Insects Caught in the Trap

Insects	Number of Insects from Order	Number of Insects from Family	Number of Insects	Percent of Diptera	Percent of Total
EPHEMEROPTERA	1				0.1
Baetidae		1			
Callibaetis fluctuans			1		
ODONATA	6				0.6
Lestidae		1			
Lestes eurinus			1		
Coenagriidae		4			
Enallagma boreale			1		
Nehalennia irene			2		
Ischnura verticalis			1		
Libellulidae		1			
Sympetrum vicinum			1		
HEMIPTERA	1				0.1
Saldidae		1			
Saldula pallipes			1		
TRICHOPTERA	6				0.6
Leptoceridae		6			
Oecetis inconspicua			6		
LEPIDOPTERA	1				0.1
Pyralidae		1			
Synclita obliteralis			1		
DIPTERA	1,390				98.5
Tipulidae		1		0.1	
Dolichopeza subalbipes			1		
Culicidae		330		23.7	
Chaoborus flavicans			328		
Chaoborus punctipennis			1		
Aedes fitchii			1		
Tendipedidae		1,055		75.8	
Pentaneura sp.			1		
Pelopia sp.			2		
Anatopynia dyari			2		
Polypedilum sp.			1		
Tanytarsus subtendens			5		
Tanytarsus punctipes			8		
Omisus pica			251		
Tendipes dux			26		
Tendipes riparius			114		
Tendipes decorus			16		
Tendipes nervosus			27		
Tendipes sp.			85		
Calopsectra sp.			517		
Psychodidae		1		0.1	
Psychoda alternata			1		
Dolichopodidae		1		0.1	
Campsicnemus hirtipes			1		
Drosophilidae		1		0.1	
Drosophila quinaria			1		
Ephydridae		1		0.1	
Dichaeta caudata			1		
TOTALS	1,405	1,405	1,405	100.0	100.0

Ephemeroptera

Baetidae

Callibaetis fluctuans Walsh – 1 mayfly, September 6. The time of emergence of this insect is similar to that found for this species at Hamilton (Judd, 1953) and London (Judd, 1957b).

Odonata

Lestidae

Lestes eurinus Say – 1 ♂, June 11 (ROM) – Walker (1953) reports this species as being extremely local in Canada, its only previous records of occurrence in Ontario being north and east of Toronto. The present collection is the first from southwestern Ontario and its occurrence in the Byron Bog is in accord with Needham's (1903) discovery of it at the edge of sphagnum-bordered pools in New York State.

Coenagriidae

Enallagma boreale (Selys) – 1 ♀, May 27. Walker (1953) gives several records of this species in Ontario but none from southwestern Ontario or the Lake Erie counties and points out that it is the commonest species of *Enallagma* in the far north. Its presence in the Byron Bog is in accord with Walker's report (1953) that it is found in sphagnum-bordered ponds.

Nehalennia irene (Hagen) – 2 ♀ ♀, June 14, 27. Walker (1953) records this species as occurring throughout southern Ontario, inhabiting almost all still waters including bog ponds of all sorts. Its time of emergence from the Byron Bog is in accord with Walker's estimate (1953) that it reaches its peak of abundance by the middle or third week of June.

Ischnura verticalis Say – 1 ♀, August 30. The emergence of this species in August is in accord with observations by Judd (1953, 1957b) at Hamilton and London. Walker (1953) reports that it inhabits a great variety of bodies of fresh water but that its least favourable type of habitat is the sphagnum pond.

Libellulidae

Sympetrum vicinum (Hagen) – 1 ♀, August 26. The emergence of this species in August is in accord with observations by Judd (1953) at Hamilton.

Hemiptera

Saldidae

Saldula pallipes Drake – 1 bug, August 10. This species is recorded from London by Judd (1957b) who also found that *S. confluenta* occurred on floating plants of *Lemna minor*, a plant which was present in the trap on the Byron Bog.

Trichoptera

Leptoceridae

Oecetis inconspicua (Walker) – 2 ♀ ♀, July 2, 3; 4 ♀ ♀, July 1, 5, 10, 16 (ROM). Ross (1944) records collections of this species from Ontario.

Lepidoptera

Pyralidae

Synclita obliteralis Wlk. – 1 moth, August 2. This species was collected at Hamilton by Judd (1953) who records that the larva feeds on *Lemna minor*, a plant present in the trap on the Byron Bog.

Diptera

Tipulidae

Dolichopeza subalbipes (Johnson) – 1 fly, June 16 (UK). This cranefly is recorded from Connecticut by Britton (1920) and from New York by Leonard (1928). Its emergence in June is in accord with Leonard's report that it appears in June and July.

Culicidae

Chaoborus flavicans (Mg.) – 180 ♂ ♂, 148 ♀ ♀, May 20 - September 5, maximum June 23 (22 insects). This mosquito is recorded from London by Judd (1957b).

Chaoborus punctipennis (Say) – 1 ♂, June 20. This mosquito is recorded from London by Judd (1957b).

Aedes fitchii (Felt and Young) – 1 ♀, May 21. This species was found to be common at London by Judd (1954).

Tendipedidae

Pentaneura sp. – 1 ♀, August 28.

Pelopia sp. – 2 ♂ ♂, August 14, 23.

Anatopynia dyari (Coq.) – 2 ♂ ♂, June 8, 9.

Polypedilum sp. – 1 midge, September 24.

Tanytarsus subtendens Townes – 5 ♂ ♂, September 5, 6, 7, 13, 14. Townes (1945) records this species from Ontario.

Tanytarsus punctipes (Wied.) - 8 midges, August 22 - September 10, maximum August 23 (2 insects). This species is recorded by Townes (1945) from Quebec but not from Ontario.

Omisus pica Townes – 140 ♂ ♂, 111 ♀ ♀ (2 ♂ ♂, 6 ♀ ♀ USNM), May 20 - August 25, maxima June 8 (14 insects) and August 1 (13 insects). This species is recorded by Townes (1945) from several northern states and was collected by him from marshy woods.

Tendipes dux (Joh.) – 11 ♂ ♂, 15 ♀ ♀, July 29 - September 9, maximum August 31 (4 insects). This species is recorded from London by Judd (1957b).

Tendipes riparius (Mg.) – 114 ♂ ♂, August 1 - September 12, maximum August 31 (20 insects). Townes (1945) records this species from several localities in Ontario.

Tendipes decorus (Joh.) – 16 ♂ ♂, August 3 - September 1, maximum August 25 (3 insects). This species occurs at several localities in Ontario (Townes, 1945) including London (Judd, 1957b).

Tendipes nervosus (Staeger) – 10 ♂ ♂, 17 ♀ ♀, June 1 - September 3, maxima June 11 (7 insects) and August 28 (2 insects). Townes (1945) records this species from Ontario.

Tendipes sp. – 61 ♂ ♂, 24 ♀ ♀, July 31 – September 22, maximum August 31 (16 insects).

Calopsectra sp. – 6 ♂ ♂, 511 ♀ ♀, June 10 - October 6, maximum August 28 (42 insects). These small, green midges were the commonest insects trapped and emerged through most of the season.

Psychodidae

Psychoda alternata Say – 1 fly, August 31. The emergence of this fly in the Byron Bog is in accord with Curran's report (1934) that the larvae live in water.

Dolichopodidae

Campsicnemus hirtipes Lw. – 1 ♂, July 12. Collections of this species were made in July by Judd (1957b) at London.

Drosophilidae

Drosophila quinaria Lw. – 1 fly, August 4. The emergence of this fly in the trap may possibly be explained as the result of the larva feeding on decaying vegetable matter on or beneath the trap, for larvae of *Drosophila* feed on such material (Curran, 1934).

Ephydridae

Dichaeta caudata (Fallen) — 1 fly, July 20. Flies of this species were trapped in July by Judd (1953, 1957b) at Hamilton and London.

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(Received June 9, 1958)

Life-History and Natural Control in British Columbia of *Ocnerostoma piniariella* Zell. (Lepidoptera: Yponomeutidae), a Needle Miner on White Pine[1]

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Ocnerostoma piniariella Zell. is an unimportant pest of Scots pine, *Pinus sylvestris* L., in Europe. A variety, *copiosella* Frey, is found in the Swiss Alps attacking a white pine, *Pinus cembra* L., and sometimes occurs in sufficient numbers to reduce growth. Both European forms have a life-history similar to that described here for British Columbia.

In North America, specimens identified as *O. piniariella* were collected in 1882 at Ithaca, New York (Forbes, 1924). The first Canadian record was for 1922 at Abbotsford, British Columbia, from white pine (Felt, 1922). The species has since been found in British Columbia at Vancouver, Victoria, Langley, and Aldergrove. Dr. T. N. Freeman (in litt.), Entomology Division, Ottawa, has collected it at Constance Bay, South March, Ottawa, and Bells Corners, Ontario.

The moth attacks *Pinus strobus* L. in Ontario, whereas in British Columbia it is more abundant on *Pinus monticola* Dougl. and attacks ornamental *P. strobus* only sparsely. The other pine heavily attacked in British Columbia was a hybrid reported by Dr. T. M. C. Taylor, Biology and Botany Department,

[1]Contribution No. 3823, Entomology Division, Science Service. Department of Agriculture, Ottawa, Canada; in part from an undergraduate thesis submitted to the Faculty of Forestry of the University of British Columbia.

[2]Student Assistant.

University of British Columbia, to be *Pinus griffithii* McClelland (*Pinus excelsa* Wall.) X *P. strobus*. The moth was not found on either *P. griffithii* or *Pinus albicaulis* Engelm.

Descriptions of Immature Stages

Egg.—The newly laid eggs are creamy yellow with hexagonal sculpturing on the chorion and average dimensions of 0.68 mm. x 0.24 mm. (20 eggs). The egg is pointed at both ends and has a carina running from end to end, so that its shape resembles that of an overturned boat.

Larva.—The immature larva is golden brown with the sclerotizations dark brown except for the front of the cervical shield, which is pale brown (Fig. 1). The mature larva is about 7 mm. long by 0.7 mm. wide, and pale green with a pale cervical shield. The average head capsule widths of the first two instars are 0.13 mm. and 0.22 mm.; of the last two instars, 0.40 mm. and 0.52 mm. These measurements indicate that there may be five instars.

The arrangement of setae on the fourth-instar larva is shown in Fig. 1. Tubeuf (1932), in a diagram of *O. piniariella* from Scots pine, ringed all the setae or setal groups as if they are on plates; however, such plates were not present on the British Columbia specimens. The prolegs and crotchets are normally rudimentary, though the prolegs are occasionally better developed. The crotchets are typically arranged in a uniordinal circle, but vary in number so that only part of a circle may be present.

Pupa.—The pupa is about 4 mm. long and golden yellow with fine hexagonal sculpturing. The last abdominal segment is slightly flattened ventrally and is drawn out laterally into two denticulate lobes.

Life-History and Habits

Egg.—The egg is laid on the inner side of the needle at the tip. As a rule, there was only a single egg to a needle. The number of eggs laid in the upper portions of the tree was significantly higher, at the one per cent level, than lower down, so that 16 per cent of the needles on the top of the tree were attacked, 11 per cent of the needles in the middle, and only seven per cent of the needles on the bottom of the tree. Aspect and age of needle had no significant influence on egg distribution.

The first eggs were observed in the field in 1954 on August 4 and in 1955 on July 26. Peak oviposition occurred before the middle of August, but desultory egg-laying extended well into September. Incubation was about three weeks.

Larva.—The first larvae were found on August 24, 1954. The larva mines through the chorion on the underside of the egg and directly into the needle. The empty egg case becomes filled with frass and appears green at first but turns brown later. The larva mines down the needle, filling the cavity behind it with frass, until the second instar when feeding ceases for the winter. Trägardh (1915) found that larvae on Scots pine would recommence feeding in winter if the temperature was over 4.5°C, but this was not found in British Columbia. Mining is resumed again in the spring and is completed by the fourth-instar larva about the middle of May. The total length of the mine in the needle is about 60 cms. The larva now moults and chews its way out of the side of the needle. By May 18, in 1954, all larvae had left the needles and each had installed itself in the middle of a fascicle with needles bound together to form a sheath. The damaged needles dropped off the tree shortly after the larvae had left their mines. Movement from the mined needle to a fascicle by the mature larva was often completed within an hour, but quite long distances may be travelled as the larva can descend on a thread to a lower

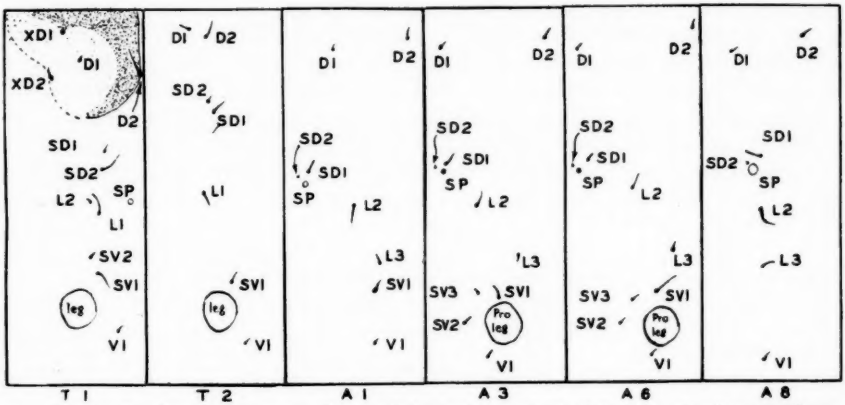

Fig. 1. Setal arrangement on the fourth-instar larva of *O. piniariella*. Setal nomenclature after Hinton, 1946.

branch. No feeding occurs in the last instar and the larva remains quiescent for almost two weeks before pupation.

Pupa.—The larva pupates in the needle sheath and the pupal stage lasts for about two months. The first pupae were found in 1954 on May 15.

Adult.—The first adults were found in the field in 1954 on July 16. The moths are fairly active during the day and pairing was observed in the early afternoon. Keller (1909) observed that they were particularly active in the early hours of the morning and Forbes (1924) caught them in a light trap. Flight is weak and follows a zig-zag pattern: it is usually no more than a flit from one needle to another. The moth rests head upwards along a needle. Oviposition occurs shortly after emergence. The sex ratio was 1:1.

Natural Control

Estimation of mortality.—Population samples were made on the basis of the number of *O. piniariella* in a hundred pine needles and the population at various times of the year is expressed on this basis in the Table. The samples were from a single tree of *P. monticola* in the Botanical Gardens of the University of British Columbia and were randomized as to height within three levels of the tree, and the needles of the three years retained on the tree were sampled equally. The mortality for any stage of *O. piniariella* was found by subtracting one population estimate from the next; this was possible as there was little overlap between one developmental stage and the next. Mortality found by this method is listed as from "unknown" cause in the Table. Mortality was also estimated directly by counting dead larvae and parasites, so that where possible the cause of mortality was identified. No estimation of adult mortality was made. Sampling errors are expressed as ± one standard error of the mean.

Main causes of mortality.—Two hymenopterous parasites were found: *Achrysocharis* sp. (Eulophidae) and *Alegina* sp. (Ichneumonidae). *Achrysocharis* sp. was found in all the collection sites in British Columbia. The adult parasite emerges in August and September and probably attacks the host shortly thereafter. It does not complete its development until the host larva has established itself in a needle sheath in May. The number of parasites reared from an individual host varied from one to six with a mean of 3.8. *Alegina* sp. adults appeared in May just as the host was moving from the needle mine to a

fascicle. Only a single parasite larva was found on any one host and larvae already parasitized by *Achrysocharis* sp. were apparently avoided. After it has consumed its host, the parasite larva spins a cocoon about twice its own length and remains quiescent until winter. It is not known when pupation occurred.

Blockages to the exits of needle tubes containing pupae accounted for some mortality, as the adults were unable to emerge successfully. This happened if another larvae pupated in the same tube, or if a larva pupated head downwards;

TABLE I

Mortality tables for the 1954–1955 generation of *O. piniariella* in bottom, middle, and top thirds of the tree canopy

Developmental stage	No. alive per 100 needles	No. dying in the stage	Cause of mortality	% mortality in stage
Bottom third				
Eggs laid, 1954	7.1±1	0.9	Unknown	12.7
Larvae (I–IV instar)	6.2	1.1	Overwintering loss (Larvae dried in needles)	17.7
Larvae leaving mines in May (V instar)	5.1±1.9	2.4	Unknown	47.1
Larvae in needle sheaths (V instar)	2.7±0.7	0.15	*Achrysocharis* sp.	5.5
		0.31	*Alegina* sp.	11.5
		0.26	Unknown	9.5
Pupae	2.0	0.26	Blockage by adelgid	13.0
		0.24	Blockage by other pupae	12.0
		0.10	Other and unknown	5.0
Moths emerged (Empty pupal cases)	1.4	–	–	–
Generation	–	5.7	–	80.3
Eggs laid, 1955	7.6±2.3			
Middle third				
Eggs laid, 1954	11.3±0.9	0.5	Unknown	4.4
Larvae (I–IV instar)	10.8	3.4	Overwintering loss (Larvae dried in needles)	31.5
Larvae leaving mines (V instar)	8.4±1.4	4.0	Unknown	47.6
Larvae in needle sheath (V instar)	4.4±1.2	0.84	*Achrysocharis* sp.	19.0
		0.11	*Alegina* sp.	2.5
		0.22	Unknown	5.5
Pupae	3.2	0.29	Blockage by adelgid	9.0
		0.32	Blockage by other pupae	10.0
		0.13	Other and unknown	4.0
Moths emerged (Empty pupal cases)	2.5	–	–	–
Generation	–	8.9	–	77.9
Eggs laid, 1955	19.1±3.1			
Top third				
Eggs laid, 1954	16.2±1.5	1.0	Unknown	6.1
Larvae (I–IV instar)	15.2	2.3	Overwintering loss (Larvae dried in needles)	15.1
Larvae leaving mines (V instar)	13.9±3.6	9.3	Unknown	66.9
Larvae in needle sheath (V instar)	4.6±0.7	3.7	*Achrysocharis* sp.	8.0
		0.39	*Alegina* sp.	8.5
		0.44	Unknown	9.5
Pupae	3.4	0.44	Blockage by adelgid	13.0
		0.14	Blockage by other pupae	4.0
		0.14	Other and unknown	4.0
Moths emerged (Empty pupal cases)	2.7	–	–	–
Generation	–	13.5	–	71.0
Eggs laid, 1955	21.3±2.6			

and commonly the blockage was caused by an adelgid filling the needle tube with wax and offspring. The adelgid had an affinity for the needle tubes, perhaps as they were a sanctuary from larger predators. These blockages also resulted in parasite mortality.

Most of the mortality occurred while the larva was searching for a pupation site and may have been caused by predation. The cause of the overwintering mortality that resulted in dried and shrivelled larvae in the needles is also unknown. The mortality over the whole year was a little less at the top of the tree than lower down but this was not apparently caused by the absence of any particular mortality factor.

The population level of *O. piniariella* is usually much lower in Europe than in British Columbia and the species is heavily attacked (up to 75 per cent) by a hymenopterous parasite, *Ageniaspis fuscicollis* (Dalm.) (Encyrtidae) (Trägardh, 1914), that has not been found in North America.

Summary

The European needle miner *O. piniariella* occurs on white pine in British Columbia and Ontario. The eggs are laid on the tips of pine needles in August and hatch in September. The larva mines a single needle until May. When it reaches the last instar it leaves the mine and moves to a fascicle which it binds together into a protective sheath. No feeding is done during this instar; pupation occurs two weeks later, inside the needle sheath. The adult emerges in August.

The moth destroyed about 11 per cent of the needles on a tree studied. Two parasites, *Achrysocharis* sp. and *Alegina* sp., were found attacking the larva. The heaviest mortality occurred from unknown causes while the larvae were seeking a pupation site. Mortality was also caused by a species of adelgid and by other pupae blocking the needle sheaths so that the moths could not emerge.

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Book Review

The Faunal Connections Between Europe and North America. By Carl H. Lindroth, 344 pp., 61 figs. John Wiley & Sons, Inc. 1957, Price $15.00.

This is a fascinating book which describes various possible methods by which the similarities which exist between European and American fauna, and flora, can be explained. All aspects are dealt with, from circumpolar and relict species to those accidentally and purposely transported by man.

The historical section describing the accidental introduction of various species of both animals and plants in the ballast carried by fishing supply vessels from England to Newfoundland is particularly intriguing, and would make interesting reading even for a non-zoologist.

It is a pity that the groups of animals dealt with, particularly in the Insecta, are limited, but this as the author points out is due to the lack of knowledge of most of the groups which might prove most interesting in this regard. The Apterygota is a group in point. It would presumably provide a number of examples of species which had been transported in the early days by man from Europe to North America, but they are hardly mentioned. On the other hand the Carabids, in which Lindroth has specialized, provide an unfortunately large number of the examples which he cites. This is by no means a criticism of the author, but of the general state of entomological knowledge, even in such comparatively thoroughly investigated areas as Europe and North America.

Although most of his conclusions are plausible, that of the method of distribution of the Staphylinid *Micralymma marinum* Strom. by the Gulf Stream seems unsupported by the data given. It is stated that this species has been carried from the American coast to various points in Greenland, Ireland and Europe (see Fig. 32 p. 245), but it would seem that if this were true this species would be more common on the American coast than is indicated.

His reference to biological control and the species of natural enemies that have been introduced into North America from Europe is very sketchy and rather misleading. This section would have been better somewhat expanded, or omitted entirely as it has little bearing on the main theme. Of the few species of North American origin which have been accidentally introduced into Europe a noteworthy omission is *Hyphantria cunea* Dr. now a serious pest in Central Europe.

There are a few understandable errors in English, e.g. p. 241 "early Atlantic time" and p. 271 "Insect rests" for "Insect remains", but these are few and not serious. On p. 212 *Elodea canadensis* is stated to have been "probably originally cultivated in Europe and escaped" whereas on p. 241 it is said that it was brought in "unintentionally". These errors are obviously of a very minor nature; the book considers various theories put forward to account for similarities in the fauna in different parts of the world, in particularly those between Europe and North America; and the deductions from the numerous examples cited are extremely interesting. This book will be of great value to biogeographers and of considerable interest also to less specialized students of general natural history. It also clearly shows our great lack of knowledge of the detailed distribution of even some of the more common insects, and it hoped that this book will stimulate more investigations along these lines.

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